Modeling the Environmental Drivers of Coral Bleaching in Hawaii: Does Impacted Water Quality Affect Bleaching Tolerance?

NOAA FISHERIES
Pacific Islands Fisheries Science Center

Thomas Oliver, *Noah Pomeroy, Courtney Couch, Raphael Ritson-Williams, Ouida Meier, Rusty Brainard & the Hawai'i Coral Bleaching Collaborative*

NOAA CORAL REEF CONSERVATION PROGRAM

NATIONAL MARINE SANCTUARIES
HAWAIIAN ISLANDS HUMPBACK WHALE

The Nature Conservancy of Hawai'i

UNIVERSITY OF HAWAI'I MĀNOA

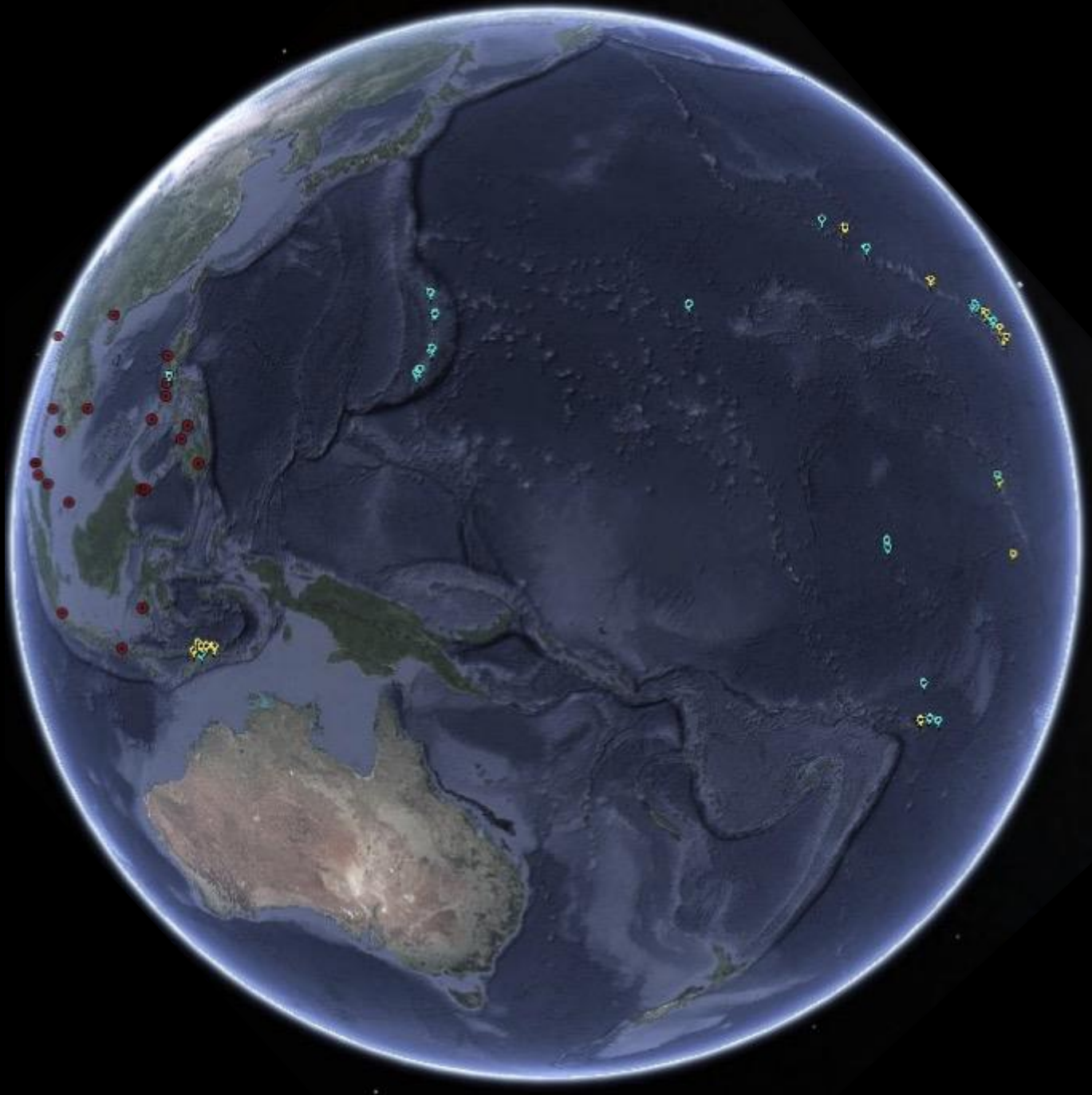
HAWAI'I INSTITUTE OF MARINE BIOLOGY

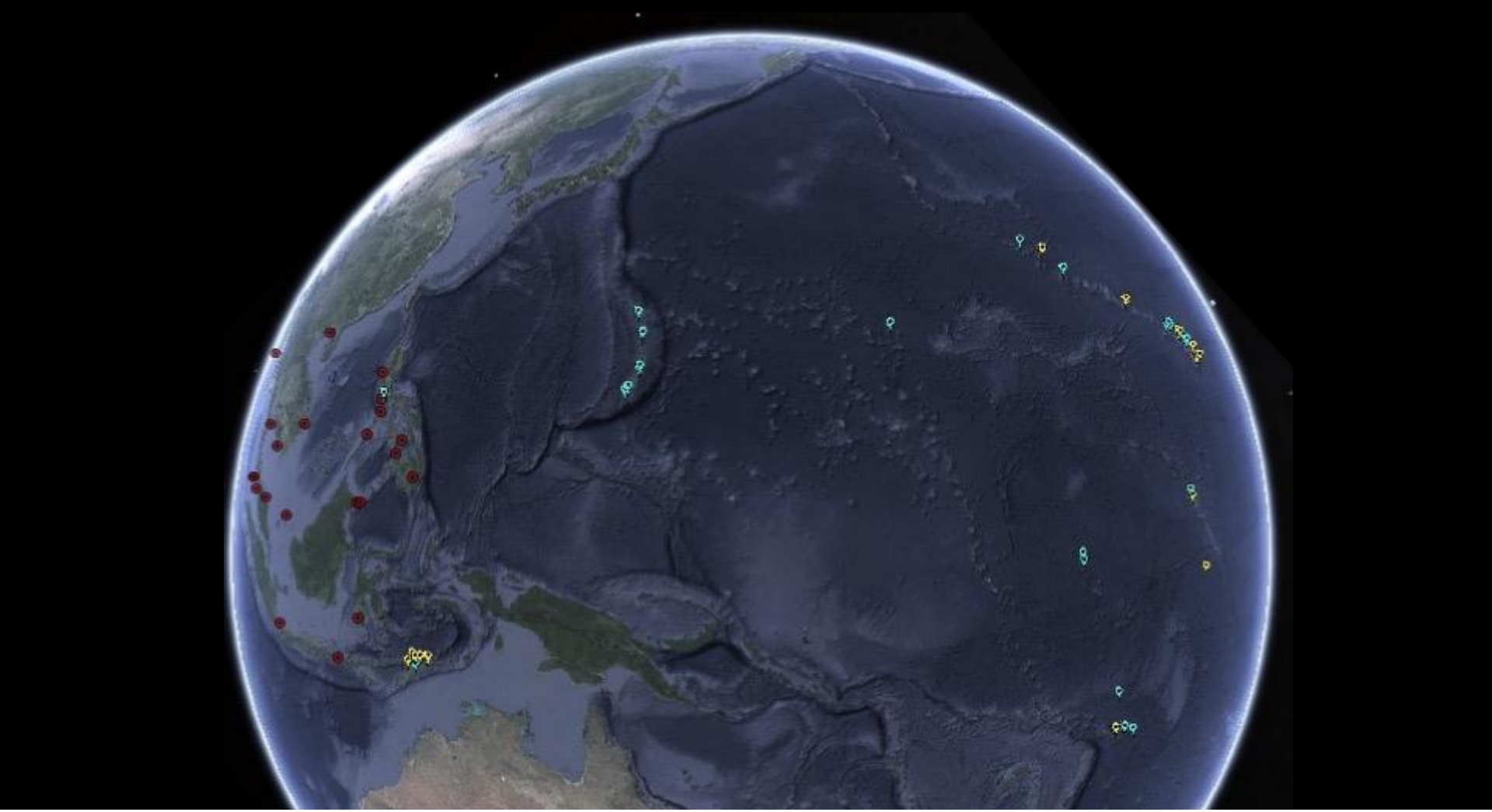
JIMAR JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH ~UH-NOAA~

NOAA FISHERIES | PACIFIC ISLANDS FISHERIES SCIENCE CENTER

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Ecosystem Sciences Division





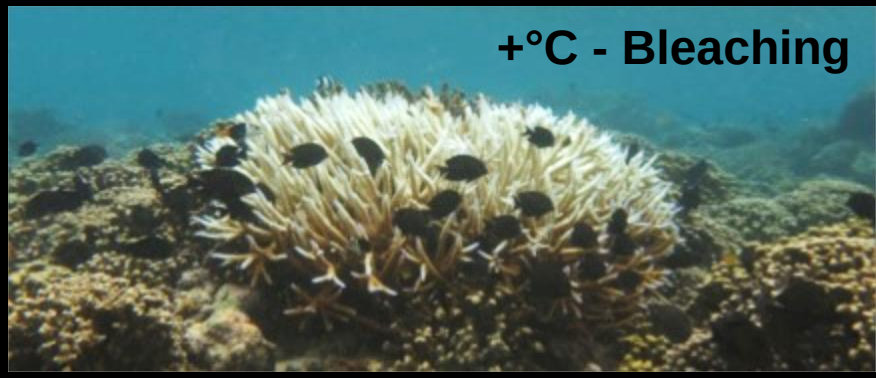
"*to provide sound* **science to enable informed** *and effective* **implementation of ecosystem-based management** *and conservation strategies* **for coral reef ecosystems** *of the U.S.-affiliated Pacific Islands Region.*"

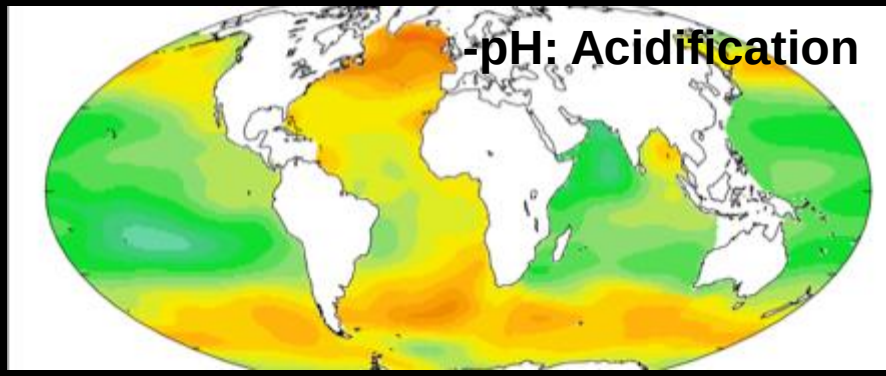
What's Happening On Coral Reefs?

What Can We *Do* About it?

Short-Term & Local

Long-Term & Global





Short-Term
& Local

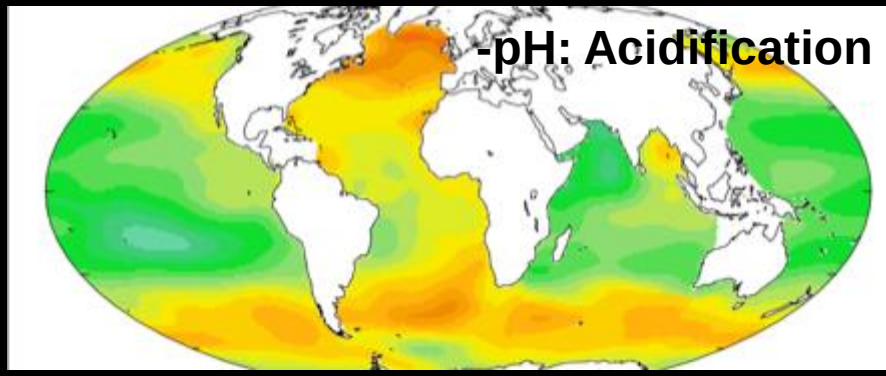
Long-Term
& Global

HARD
For Local
Managers.

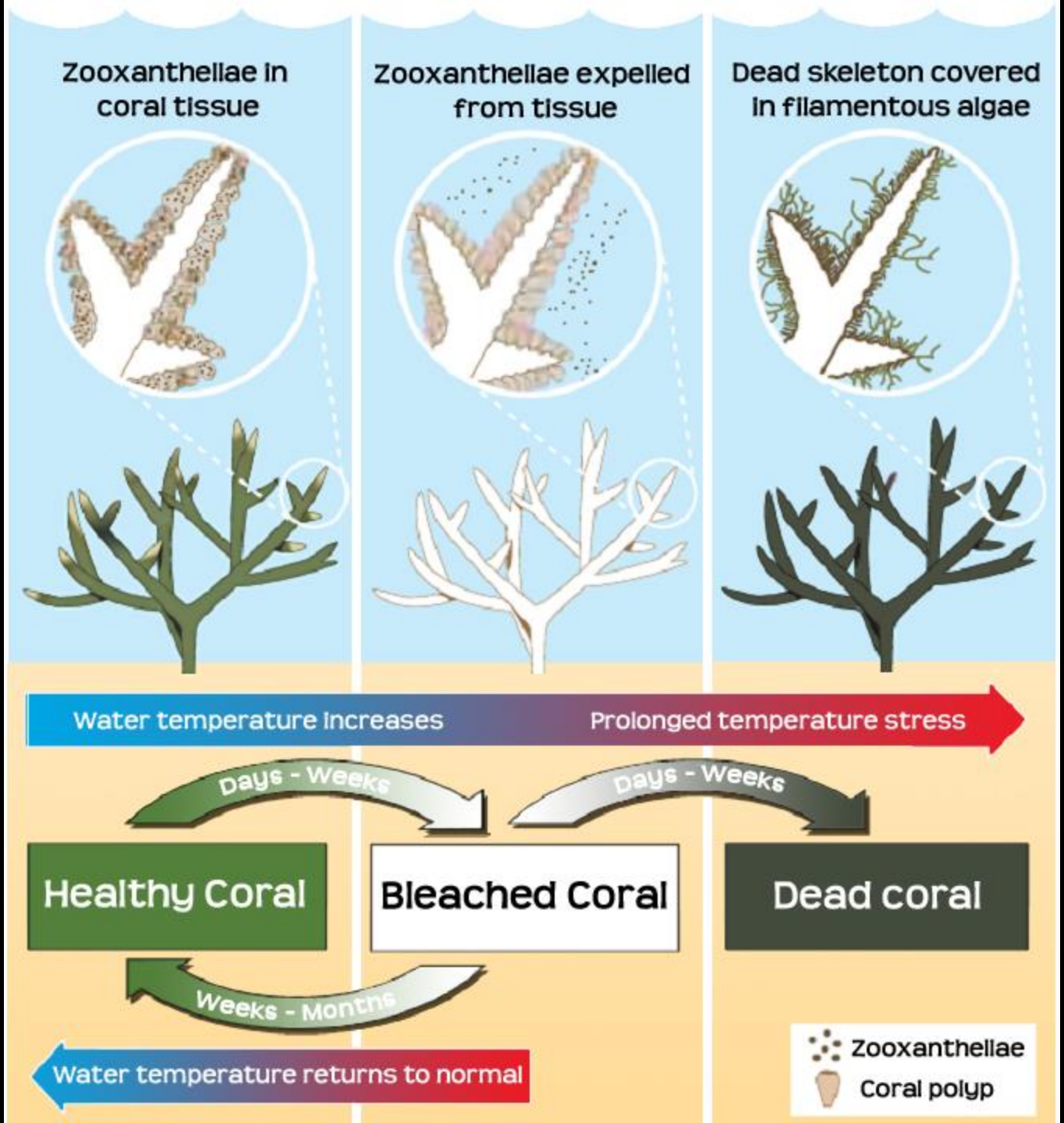
WAY
HARDER
For Local
Managers.

Short-Term & Local

Long-Term & Global

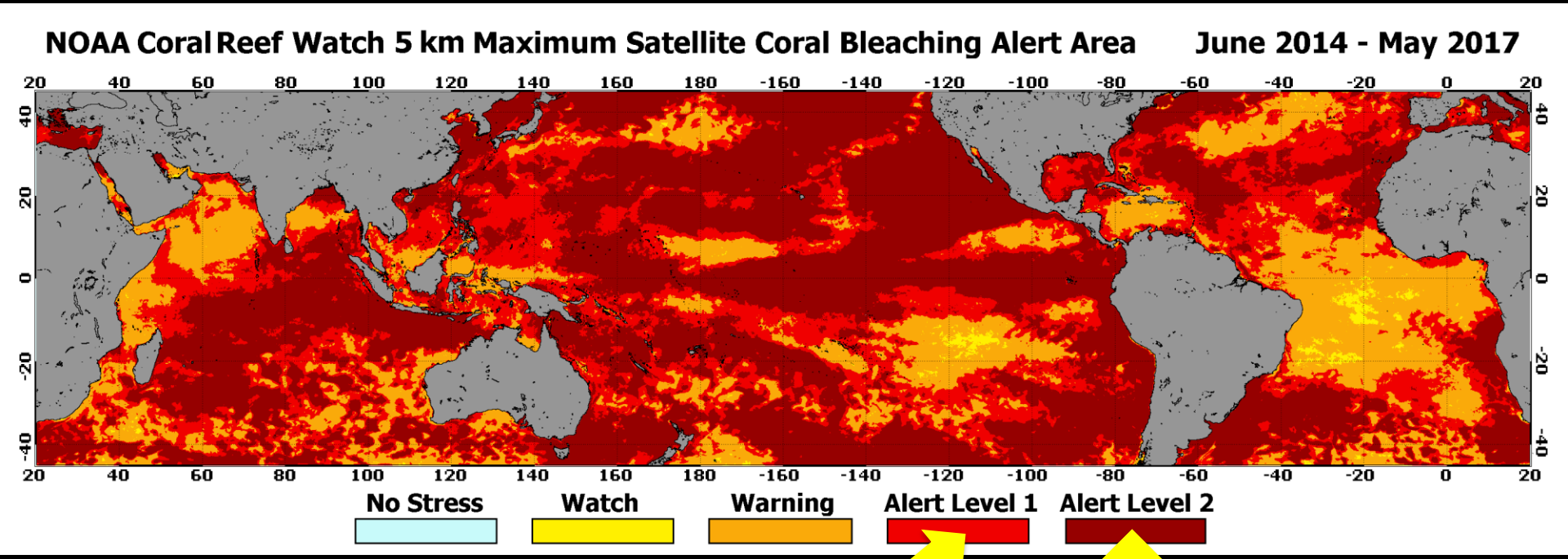


Coral Bleaching



After GBRMPA, 2008

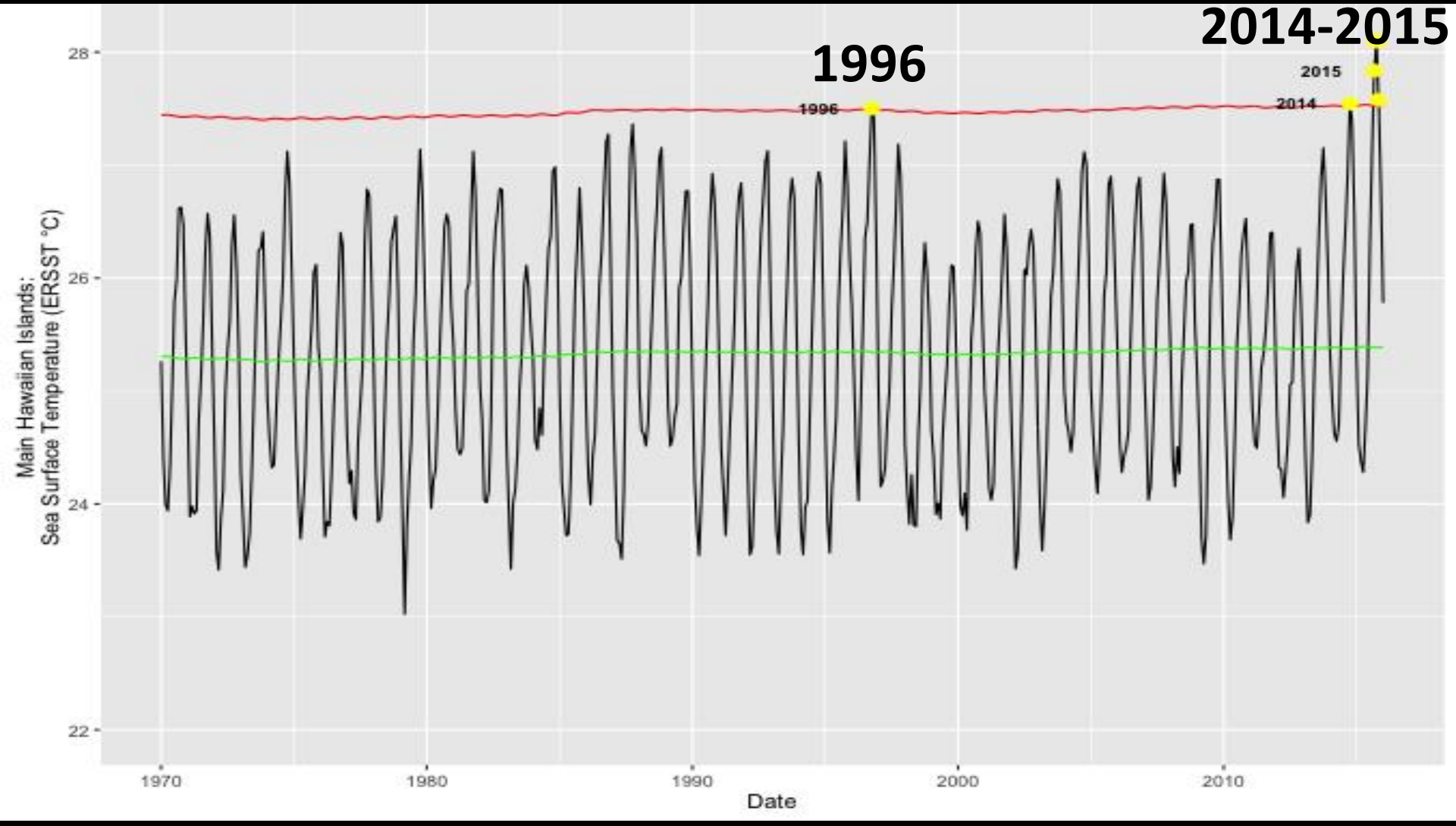
Third Global Coral Bleaching Event 2014-2017



Mass Bleaching Expected

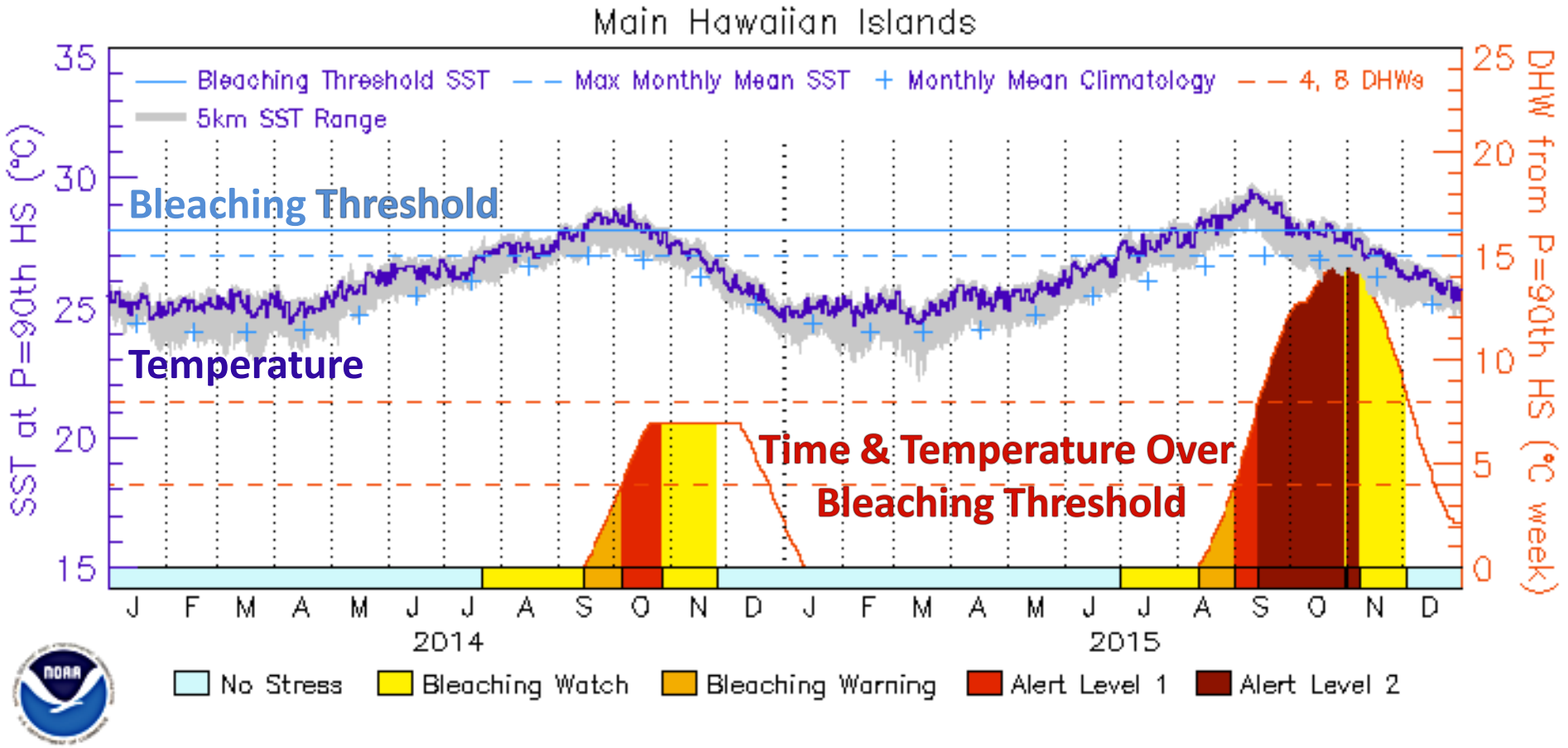
Mass Mortality Expected

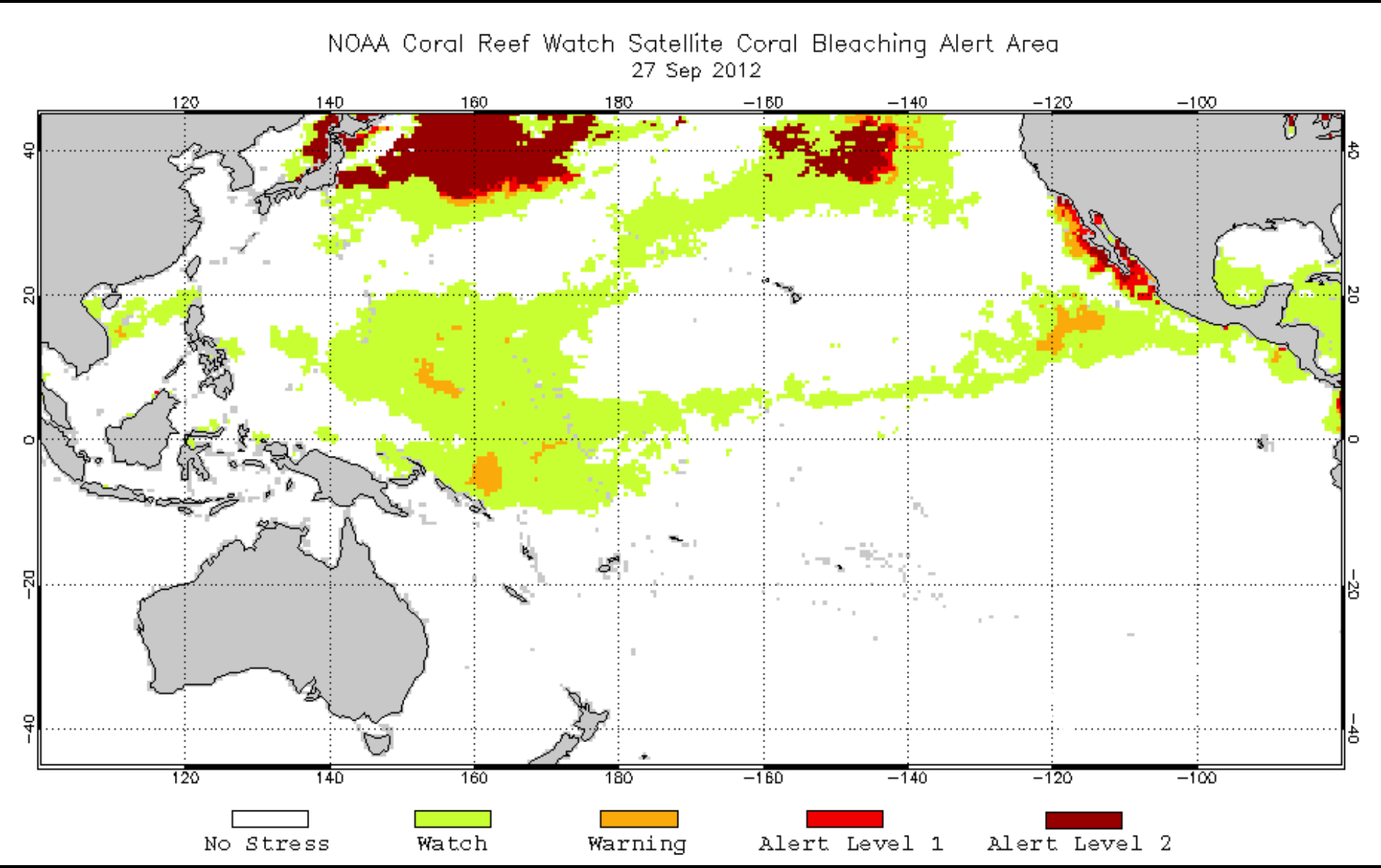
2014-2015 in the Main Hawaiian Islands: Hottest Years in ½ Century… (ERSST)

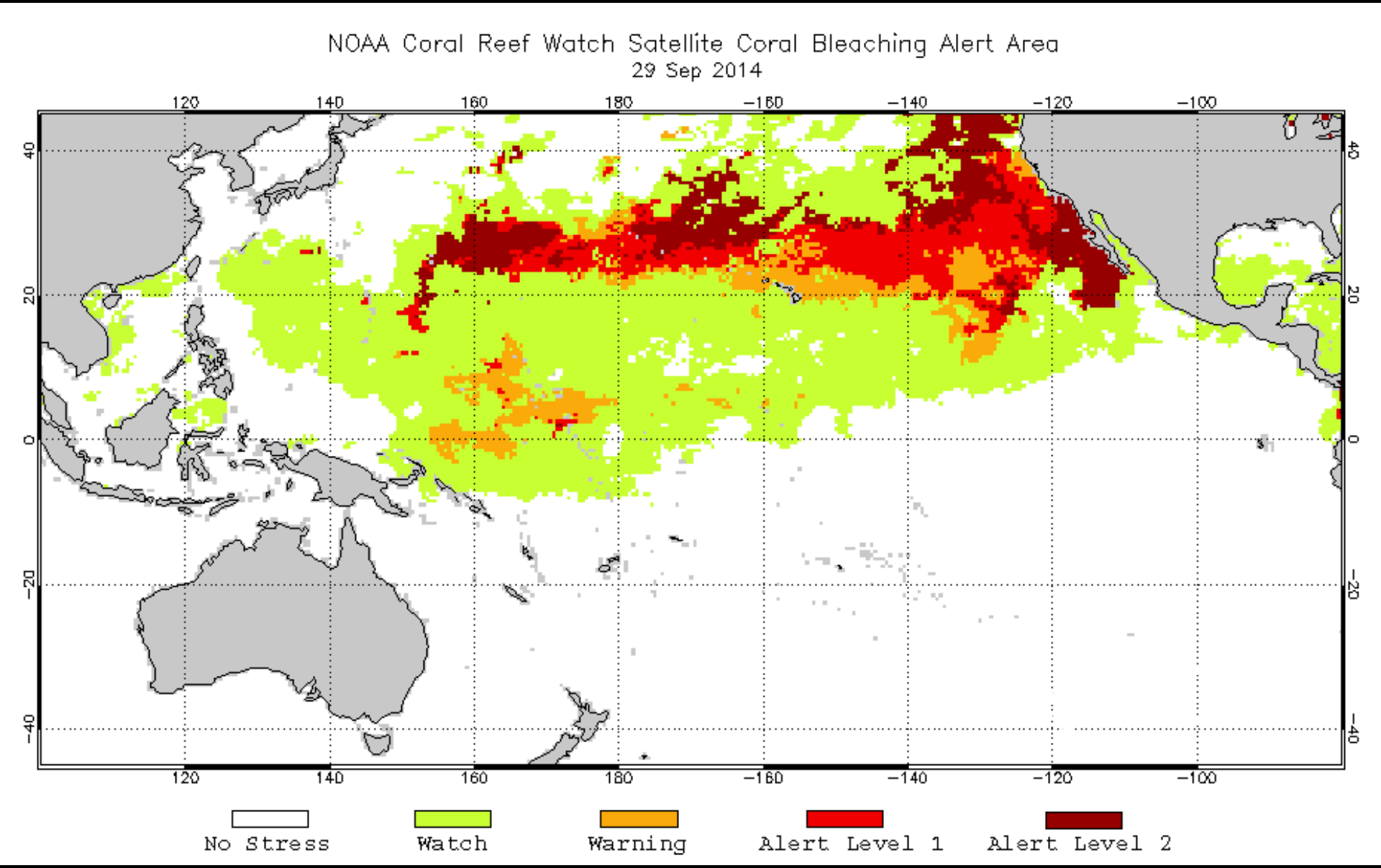


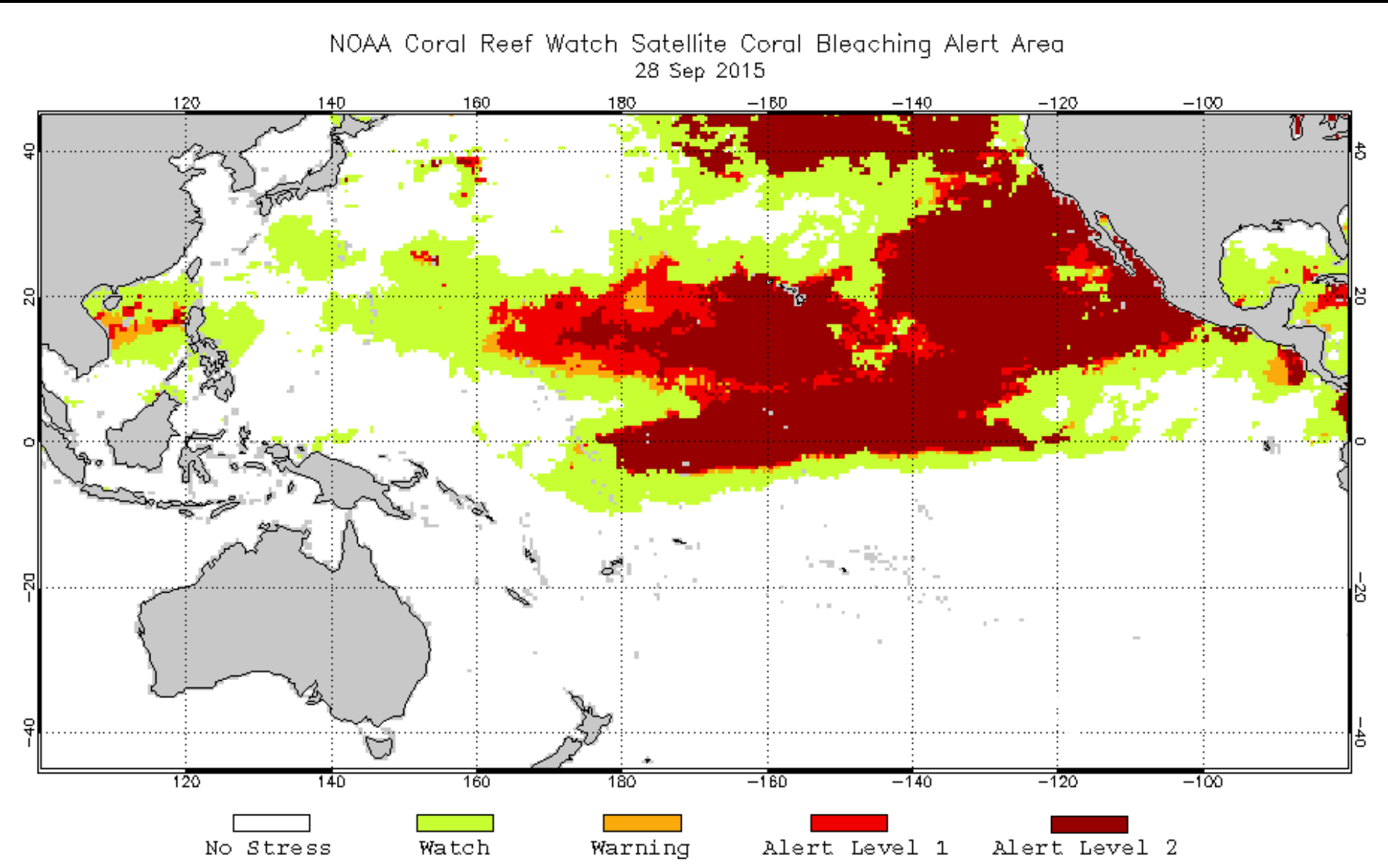
2014-2015: In Hawai‘i

Unprecedented Back-to-Back Mass Bleaching



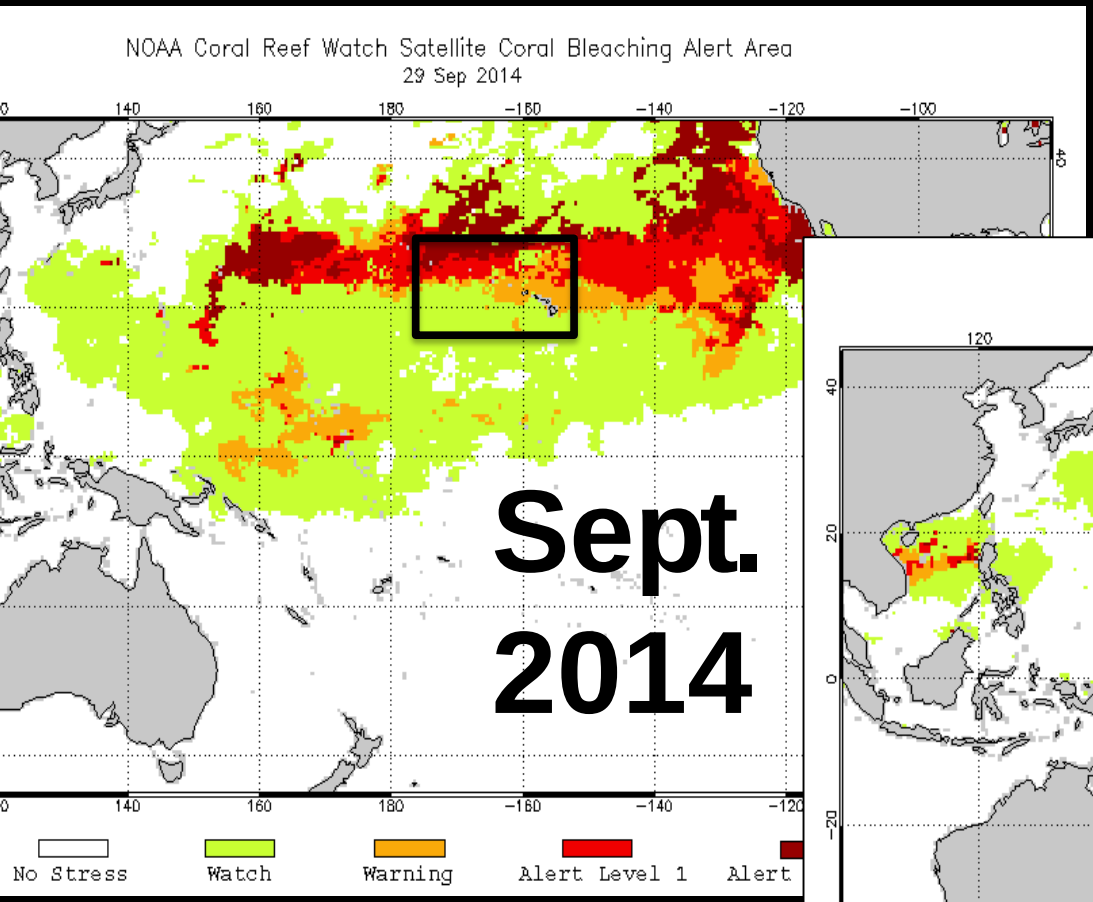

NOAA Coral Reef Watch Satellite Coral Bleaching Alert Area
27 Sep 2012
120
140
160
180
-160
-140
-120
-100
40
20
0
-20
-40
No Stress
Watch
Warning
Alert Level 1
Alert Level 2

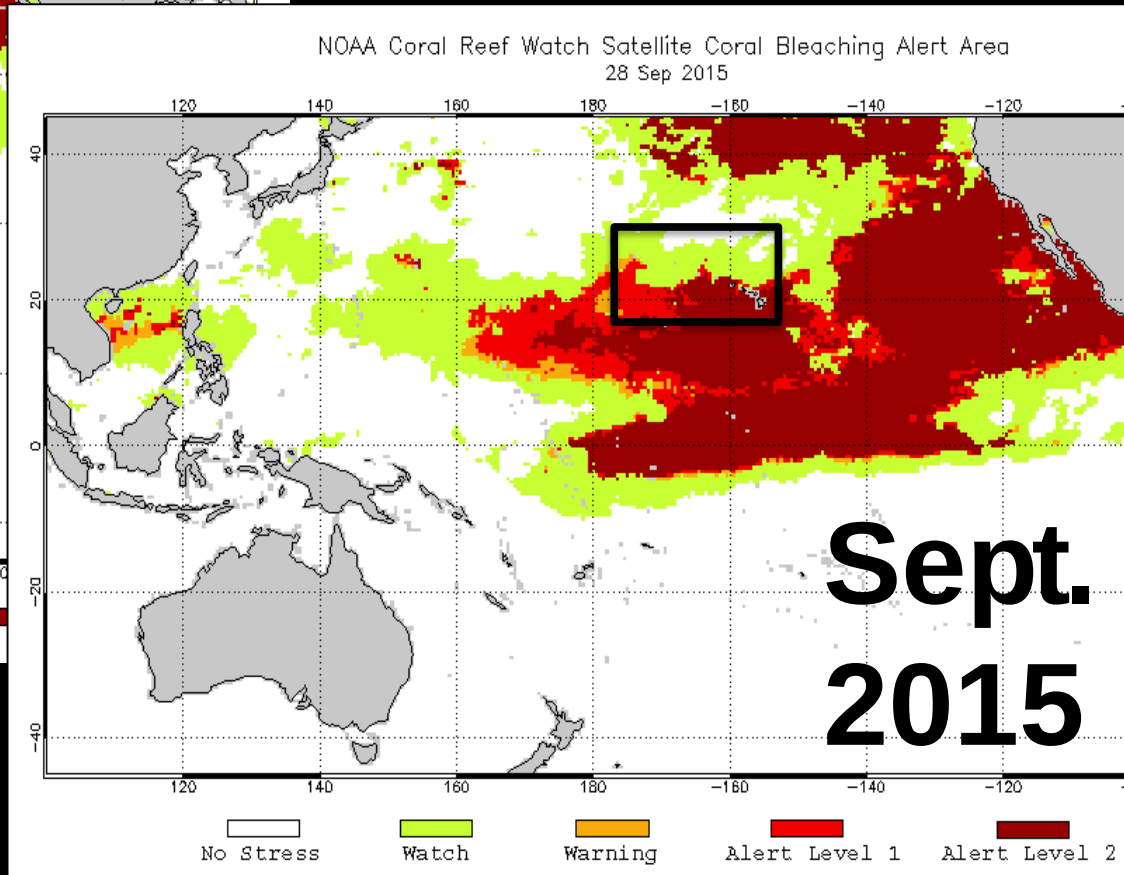

NOAA Coral Reef Watch Satellite Coral Bleaching Alert Area
29 Sep 2014
120
140
160
180
-160
-140
-120
-100
40
20
0
-20
-40
No Stress
Watch
Warning
Alert Level 1
Alert Level 2


NOAA Coral Reef Watch Satellite Coral Bleaching Alert Area
28 Sep 2015
120
140
160
180
-160
-140
-120
-100
40
20
0
-20
-40
No Stress
Watch
Warning
Alert Level 1
Alert Level 2

2014-2015: In Hawai‘i

Unprecedented Back-to-Back Mass Bleaching

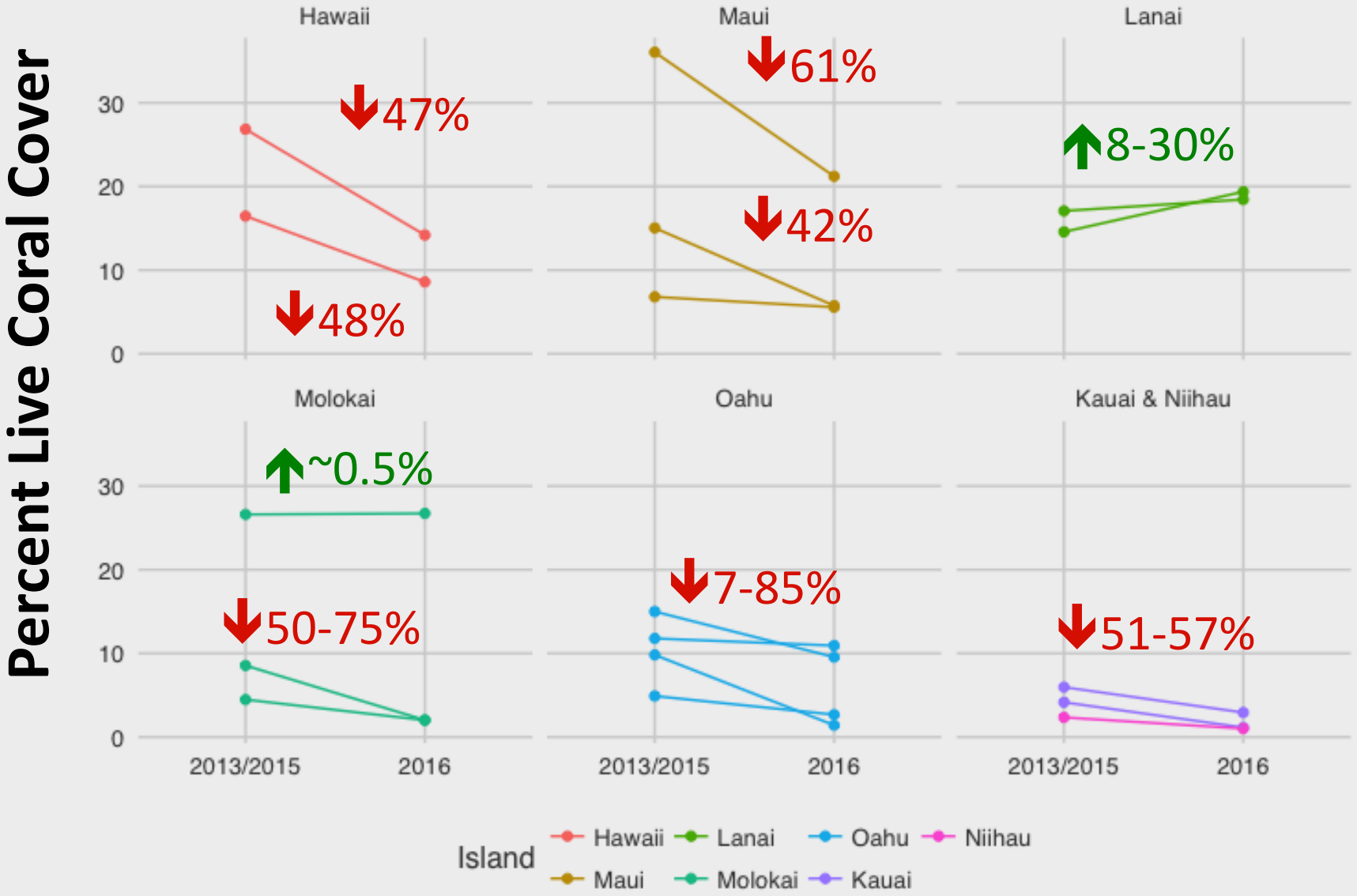




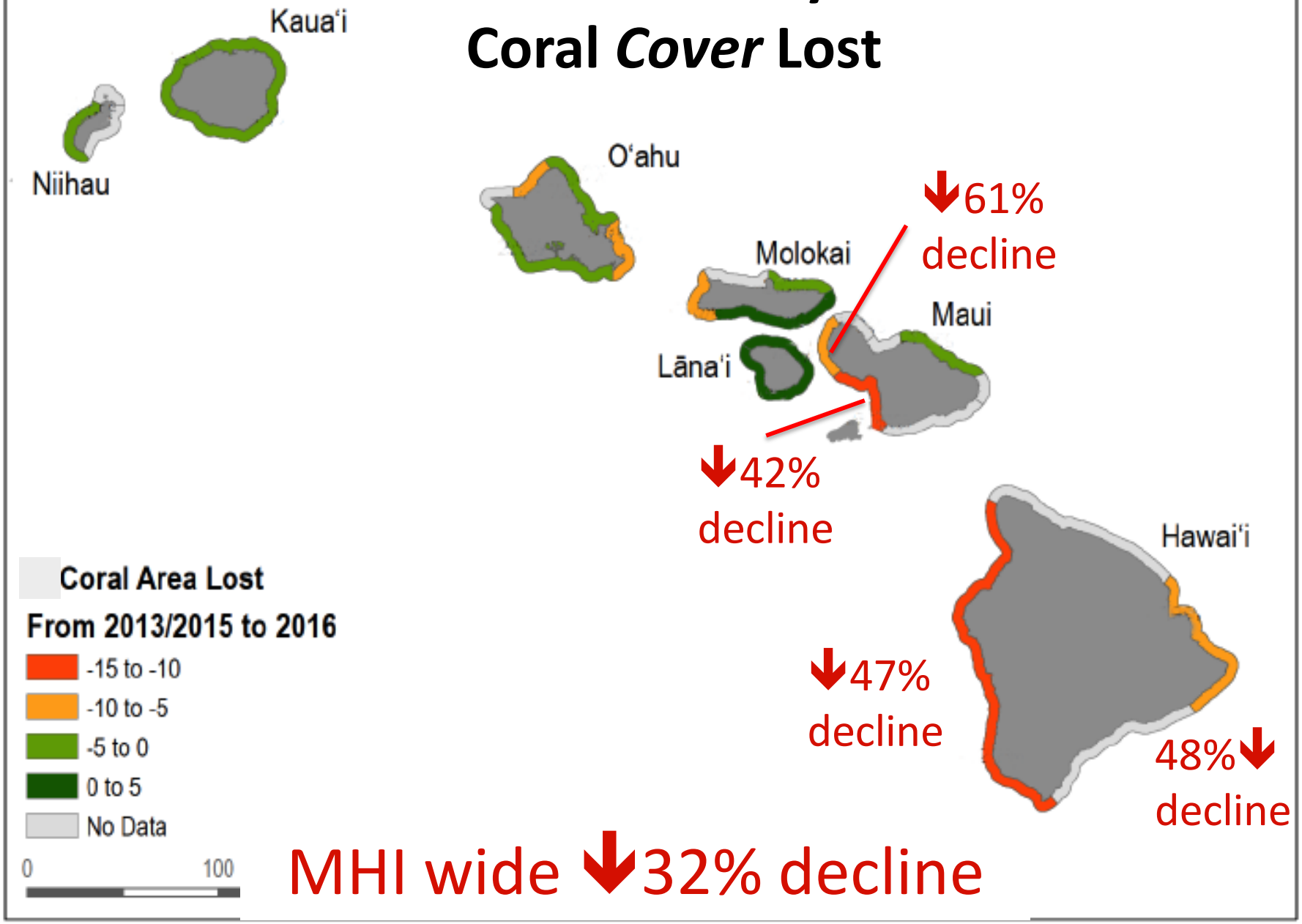
2015 in the Main Hawaiian Islands

2013-2016 Coral Mortality

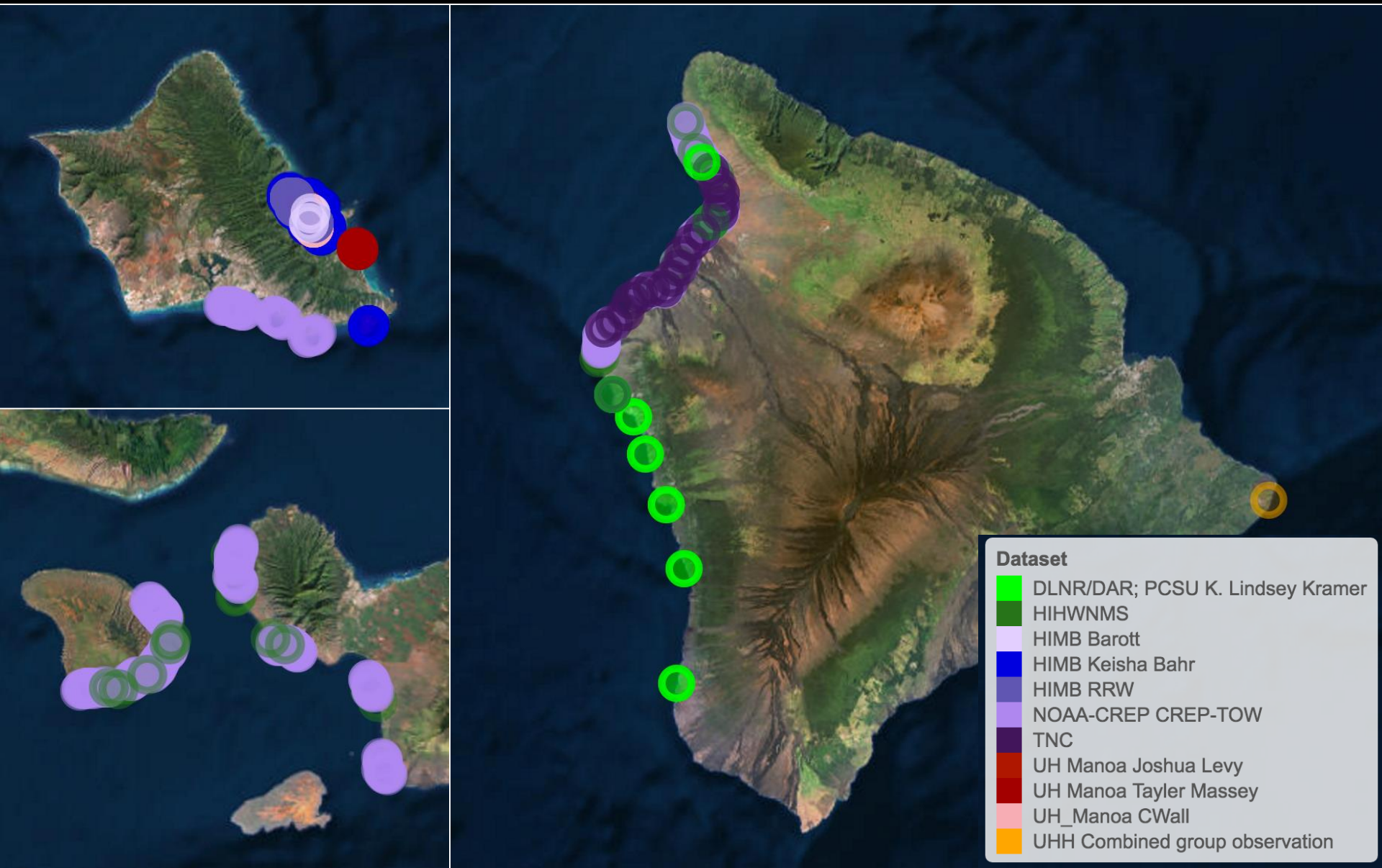
Change in Coral Cover Before and After 2015 Event



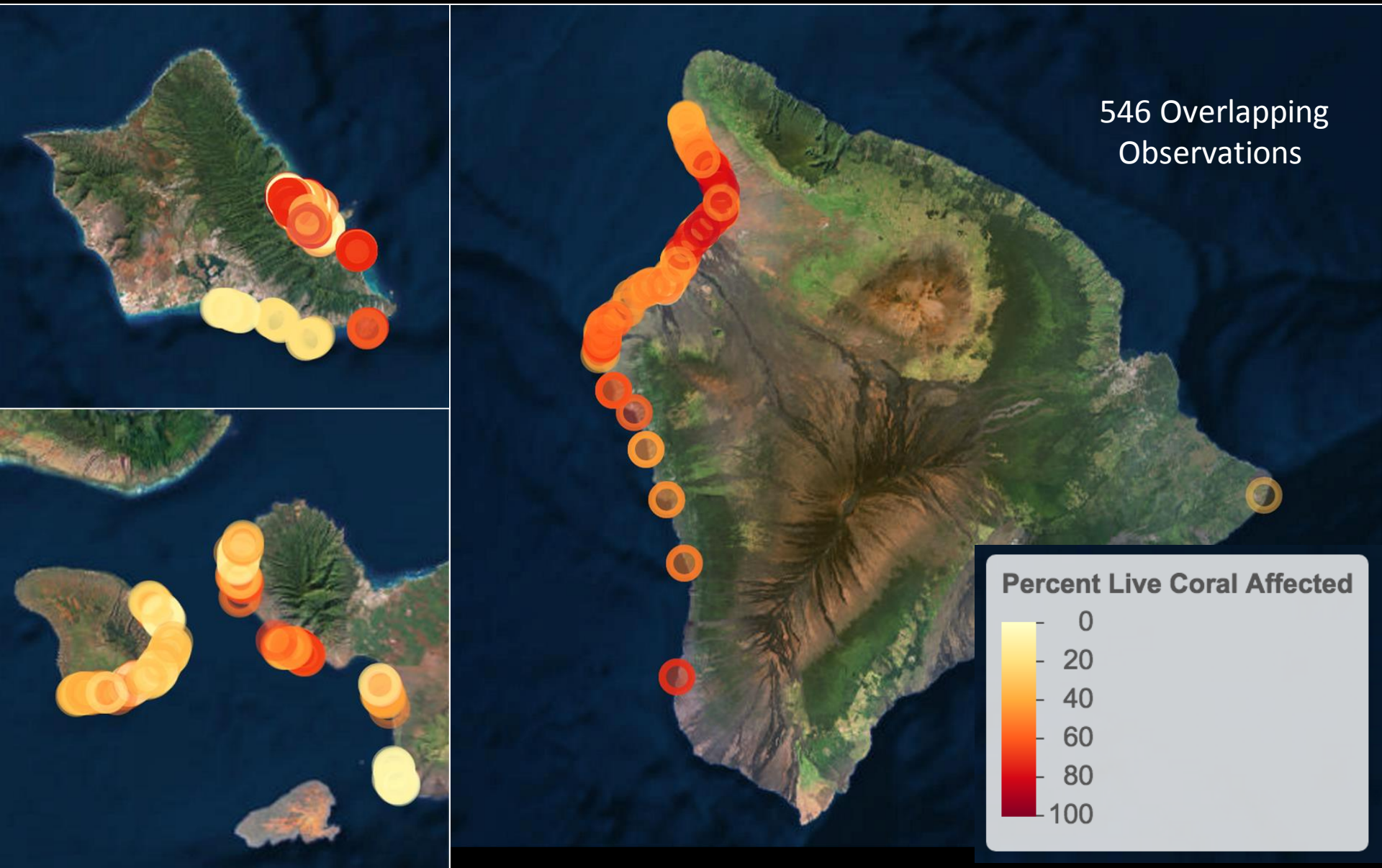
2013 to 2016 Mortality Estimates: Coral *Cover* Lost



Hawaii Coral Bleaching Collaborative Dataset: Main Hawaiian Islands, Oct-Nov 2015

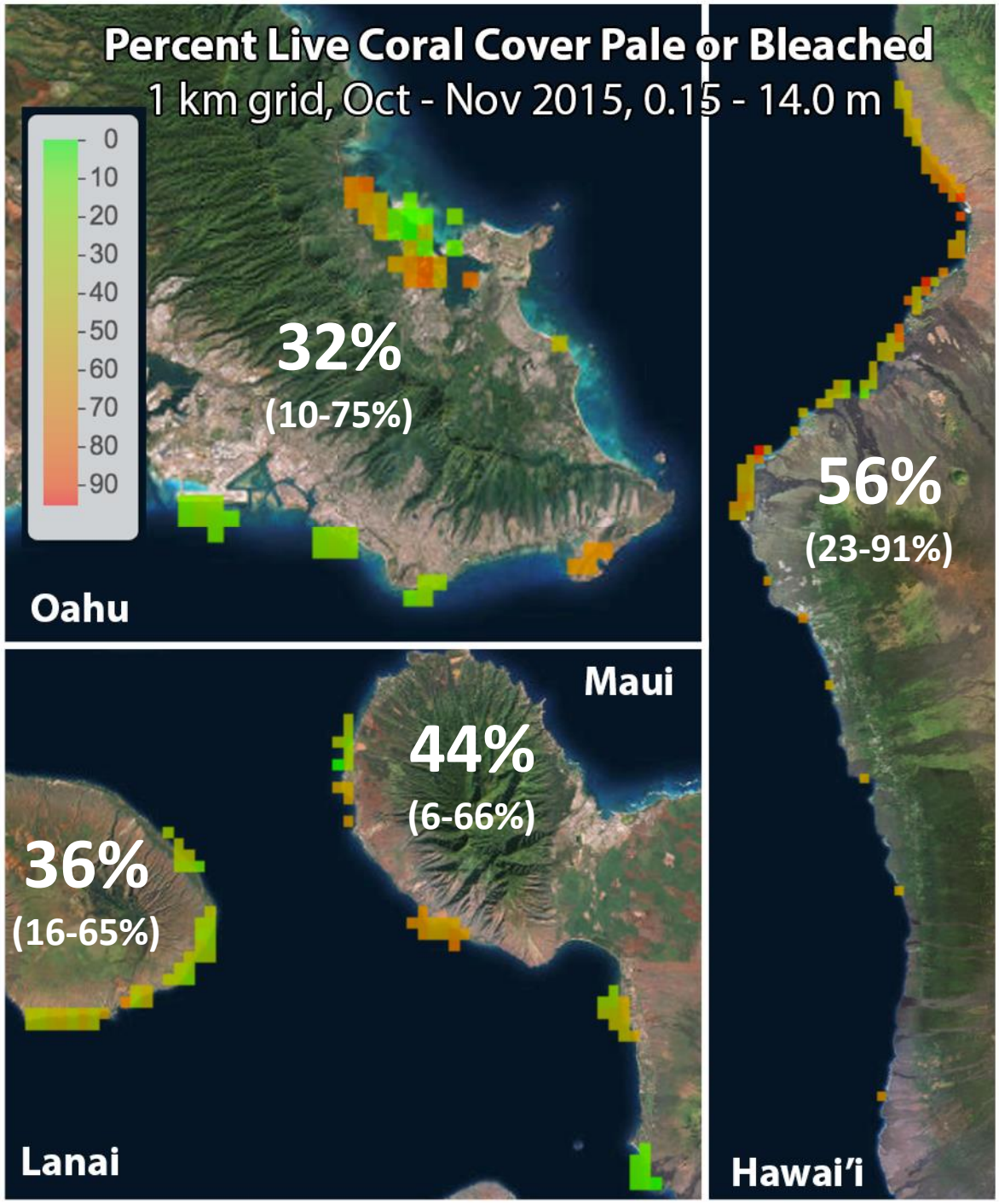


Hawaii Coral Bleaching Collaborative Dataset: Main Hawaiian Islands, Oct-Nov 2015



Nearly **half** of corals surveyed in MHI paled/bleached:

46% +/- 4% Percent Affected



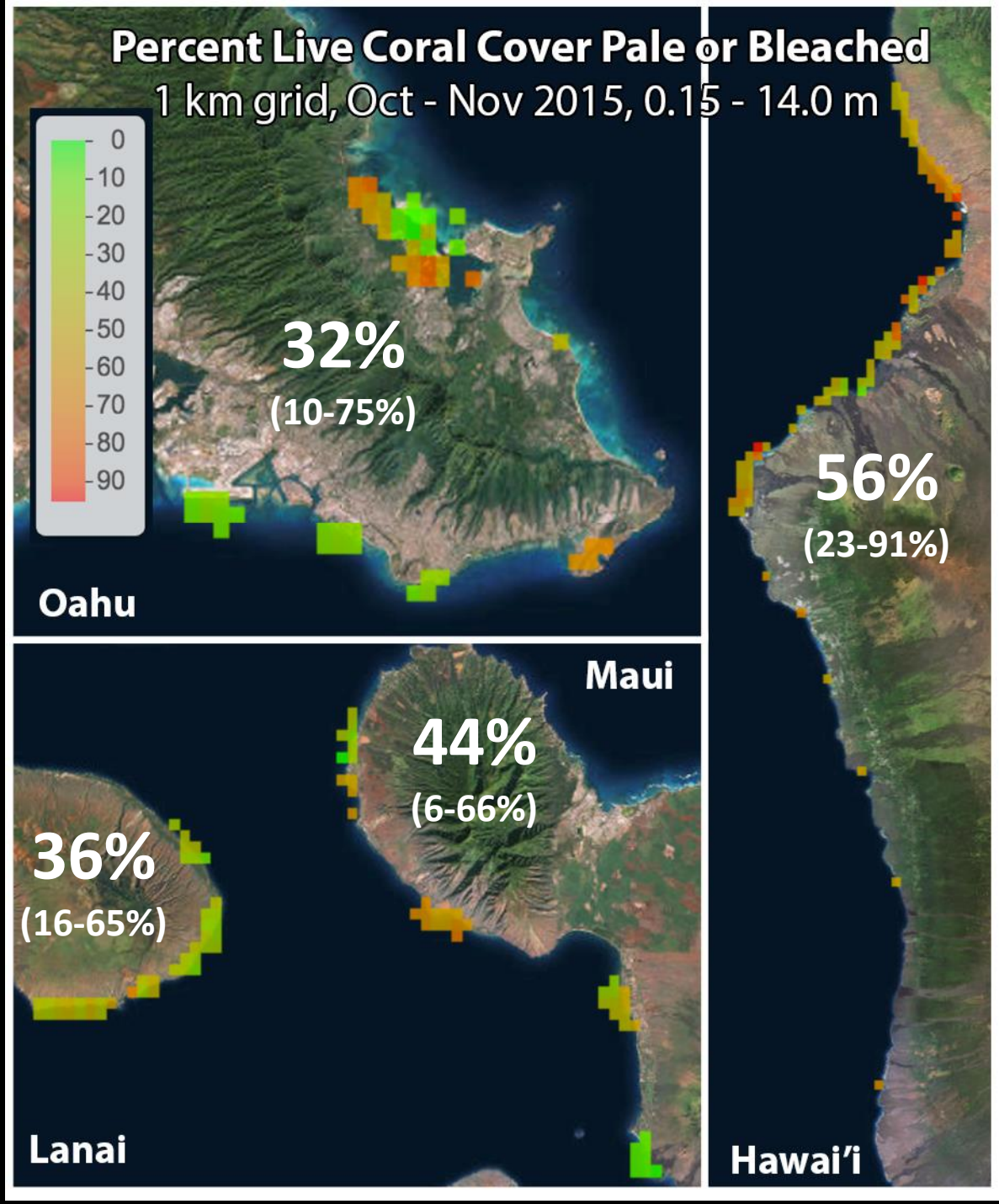
What factors correlated with more or less bleaching?

Exposure:

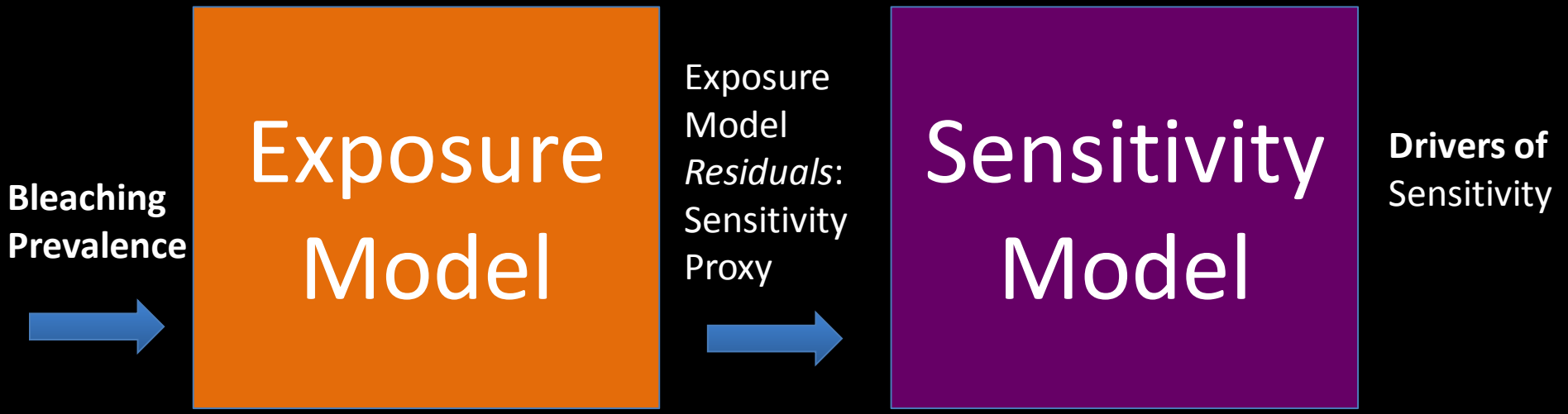
What factors triggered bleaching impacts?

Sensitivity:

What factors limited or exacerbated damage?



Model Both ***Exposure*** and ***Sensitivity***



- 2015 Data,
- Temperature, Light, Wave Exposure
- Bleaching Triggers

- 2003-2015 Data,
- Hypothesized Resistance Builders / Eroders

Tested Spatial Drivers

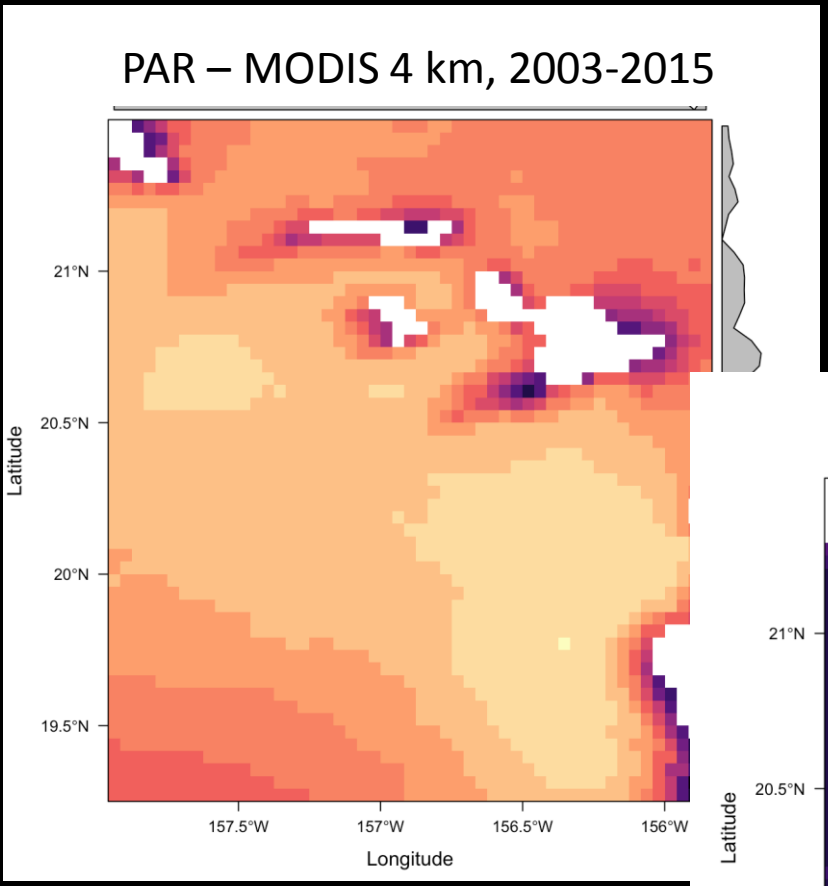
- Satellite:
  - Coral Reef Watch Degree Heating Weeks
    - v3 (Nov 1, 2015)

  Mean, Min, Max, SD, Range, Weekly Range: ***Long-Term, 2014, 2015***
  - SST (MUR 1 km Daily, 2003-2015)
  - PAR (MODIS 4 km Daily, 2003-2015)
  - K490 (MODIS 4 km Daily, 2003-2015)
  - PAR at Depth (Calculated from PAR and K490)
- Cumulative Stressor Layers (38 in Total)
  - Ocean Tipping Points / Lecky 2016
  - Fishing, Land-Based Source Pollution, Shipping, Recreation
- In-Situ:
  - Island, Region
  - Depth

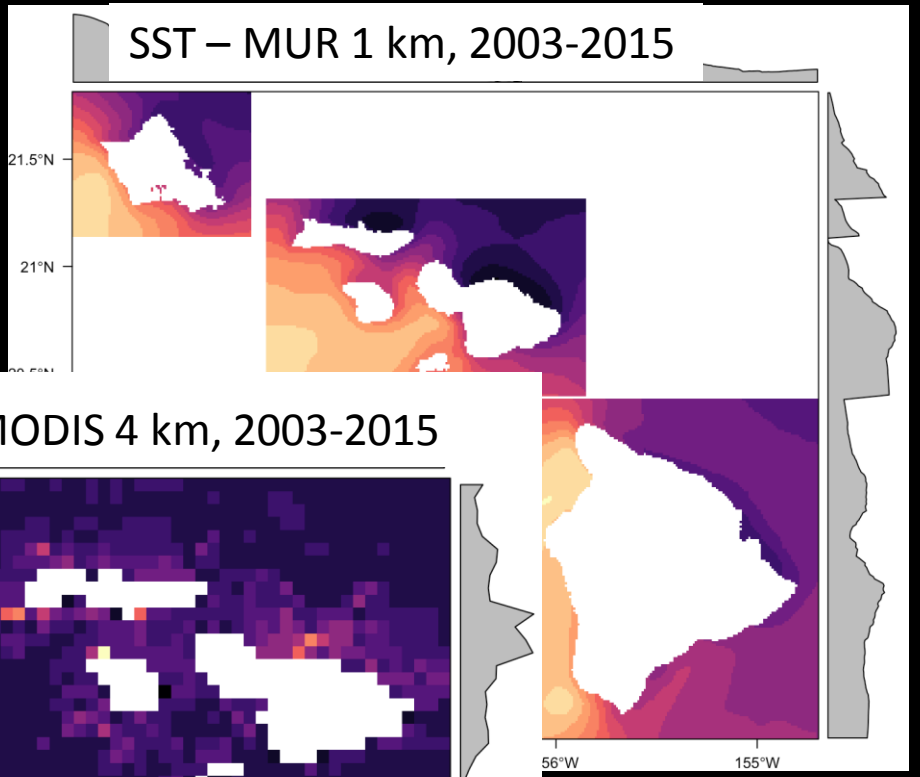
- Not Yet Included:
  - Coral Species
  - Fish Interactions

Satellite Layers

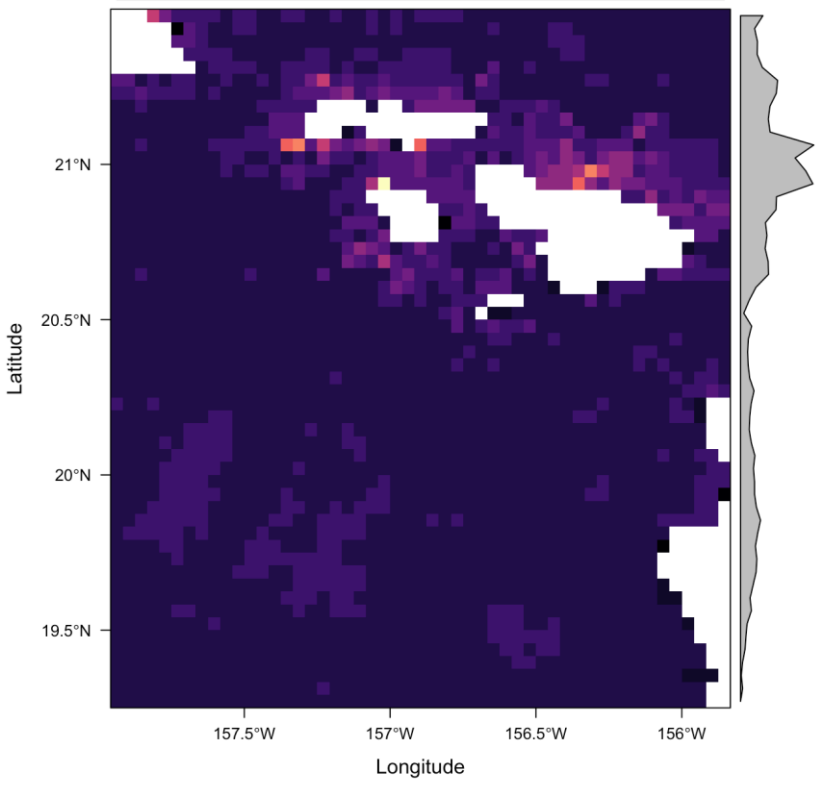
PAR – MODIS 4 km, 2003-2015



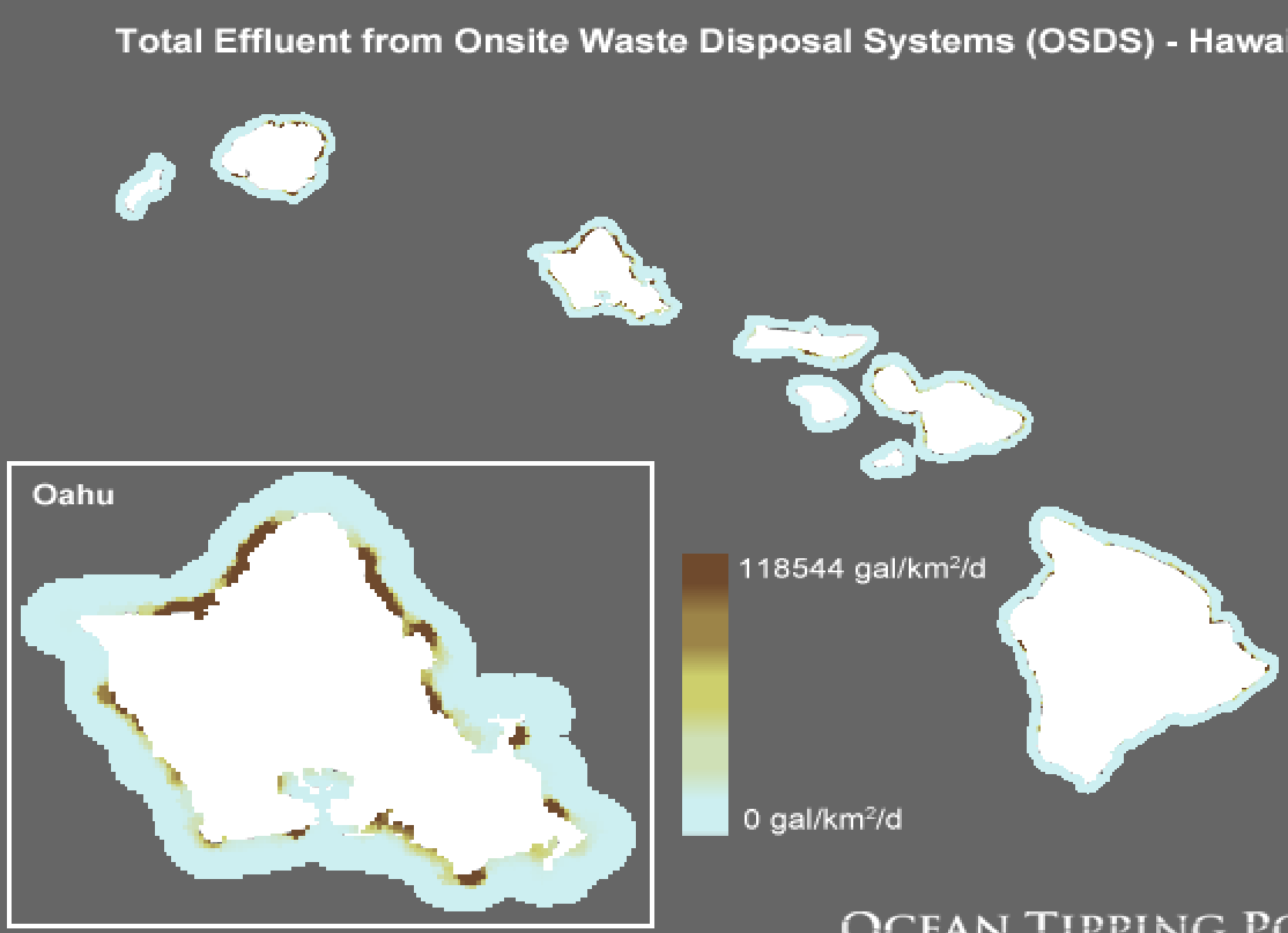
SST – MUR 1 km, 2003-2015



K490– MODIS 4 km, 2003-2015



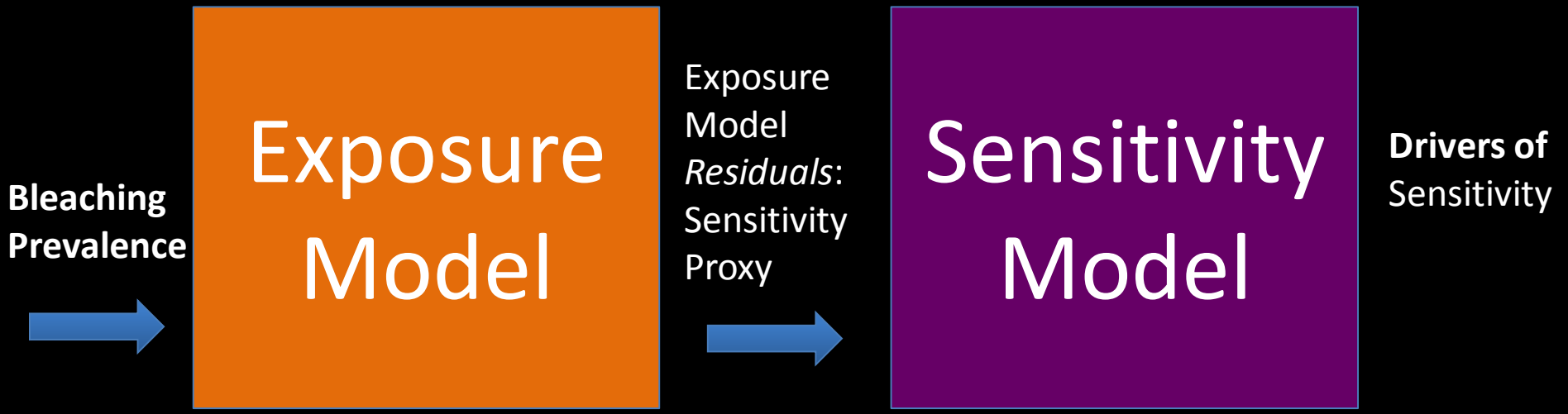
Cumulative Impact Layers



OCEAN TIPPING POINTS

What ***Factors*** Drove Corals to Bleach?

Model Both ***Exposure*** and ***Sensitivity***



- 2015 Data,
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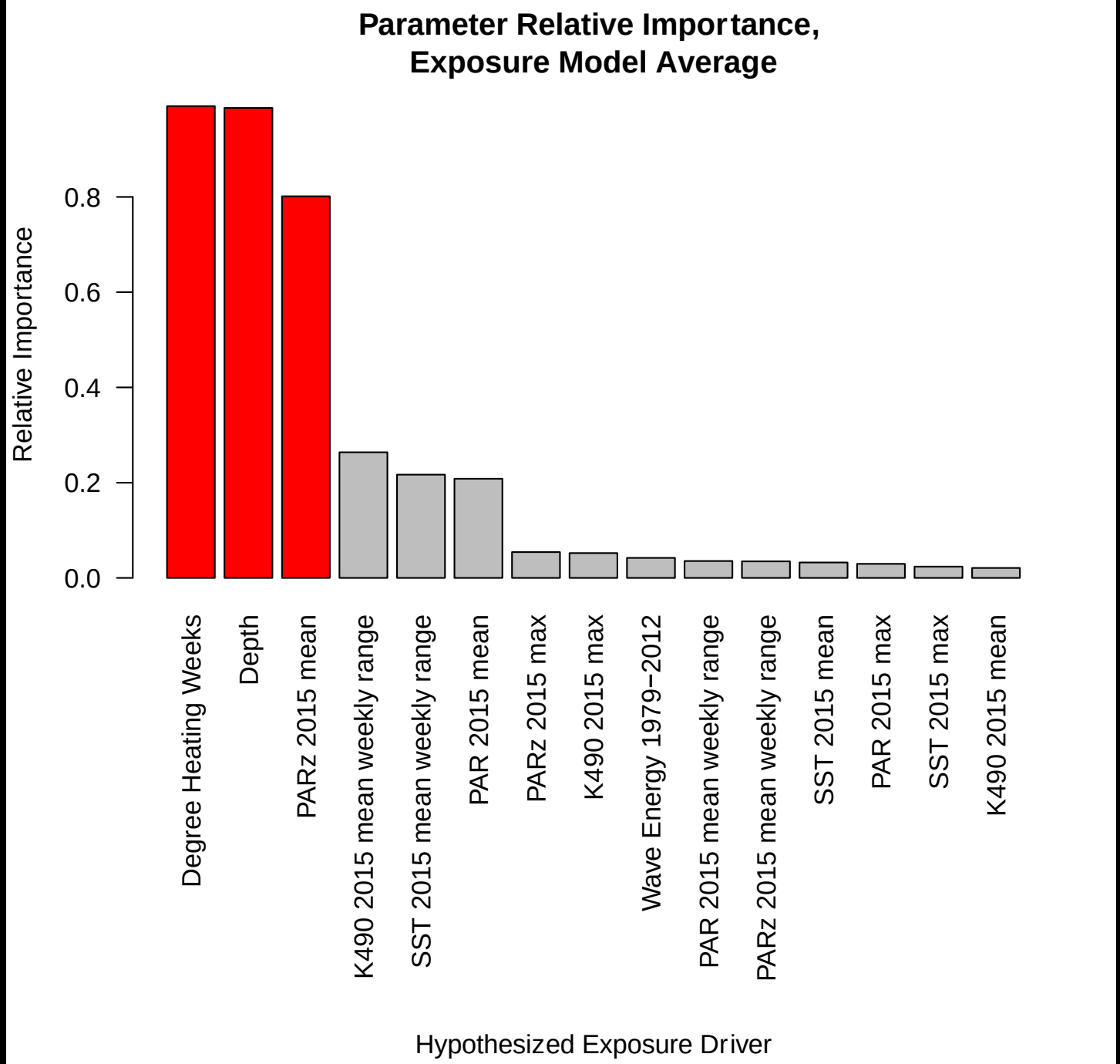
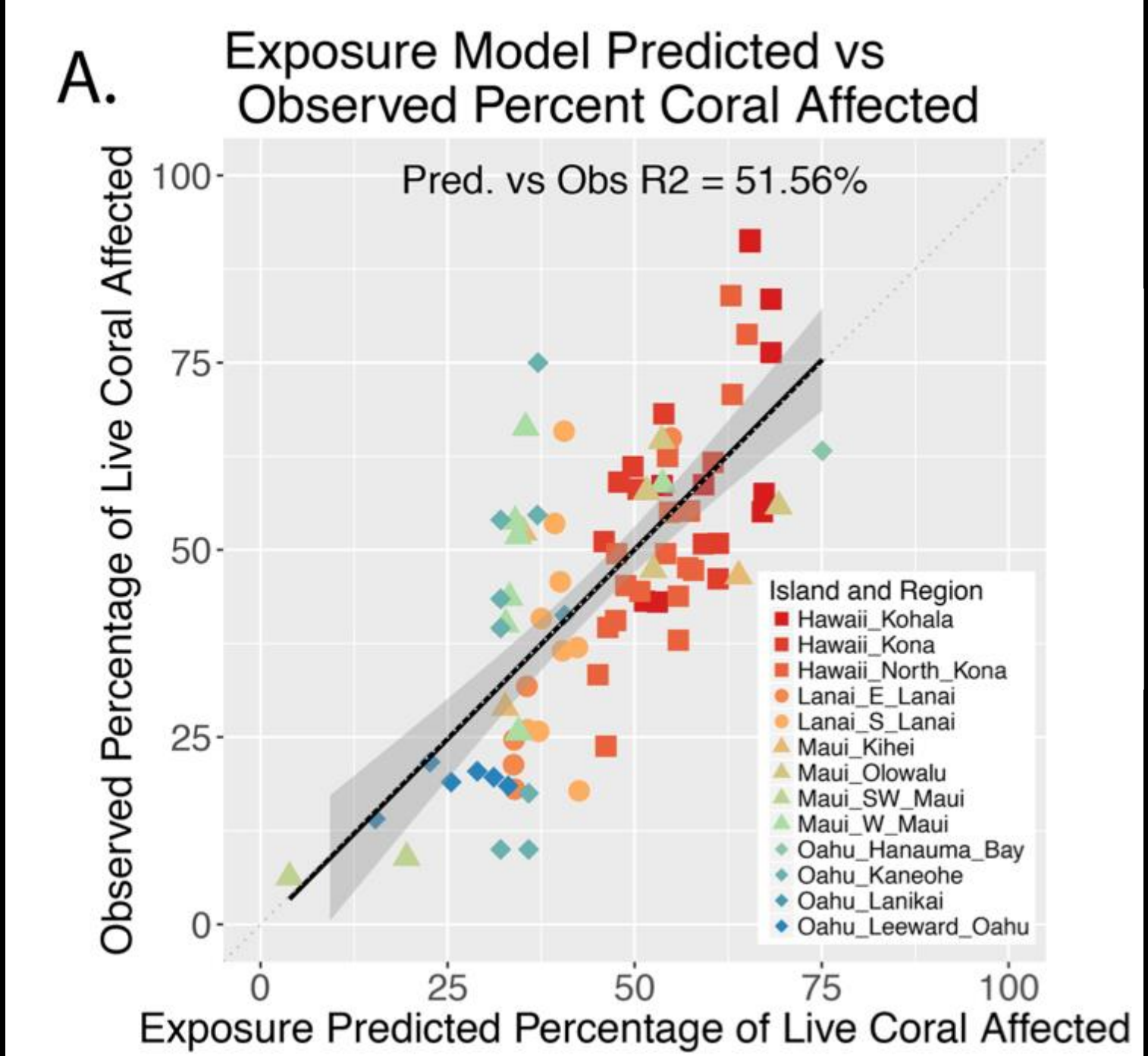
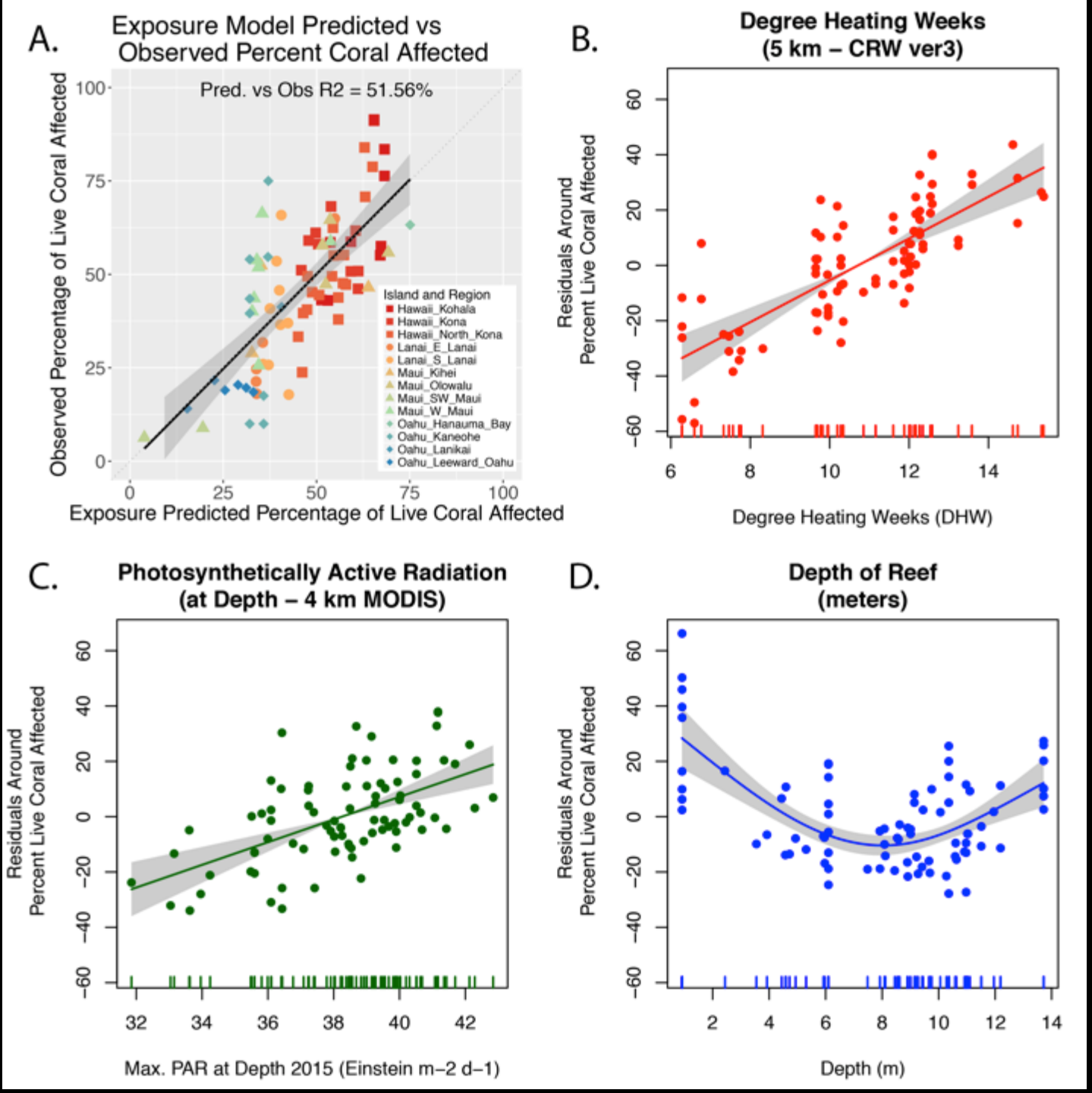
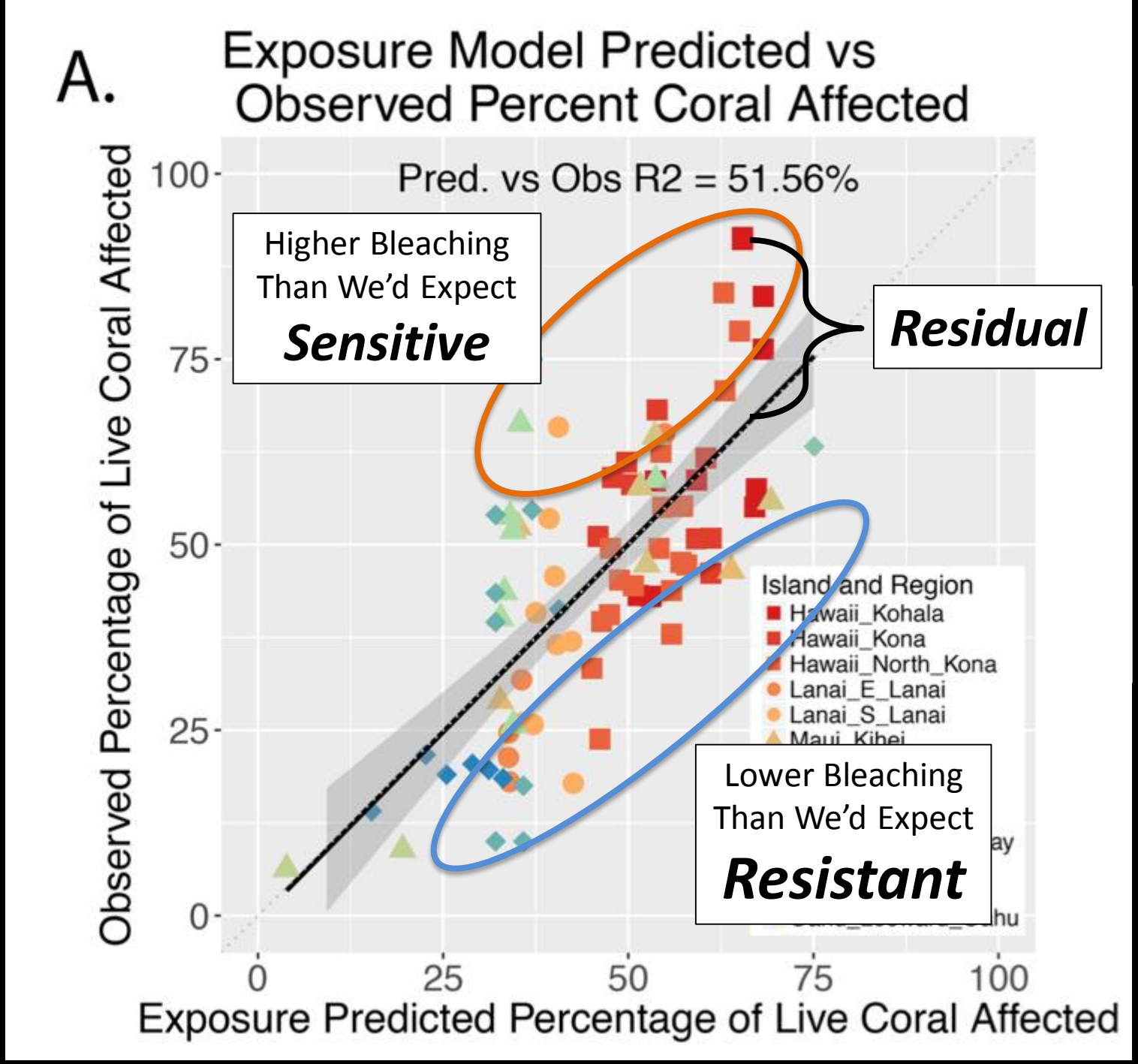
GAM Modeling, Model Selection, Weighted Model Averaging

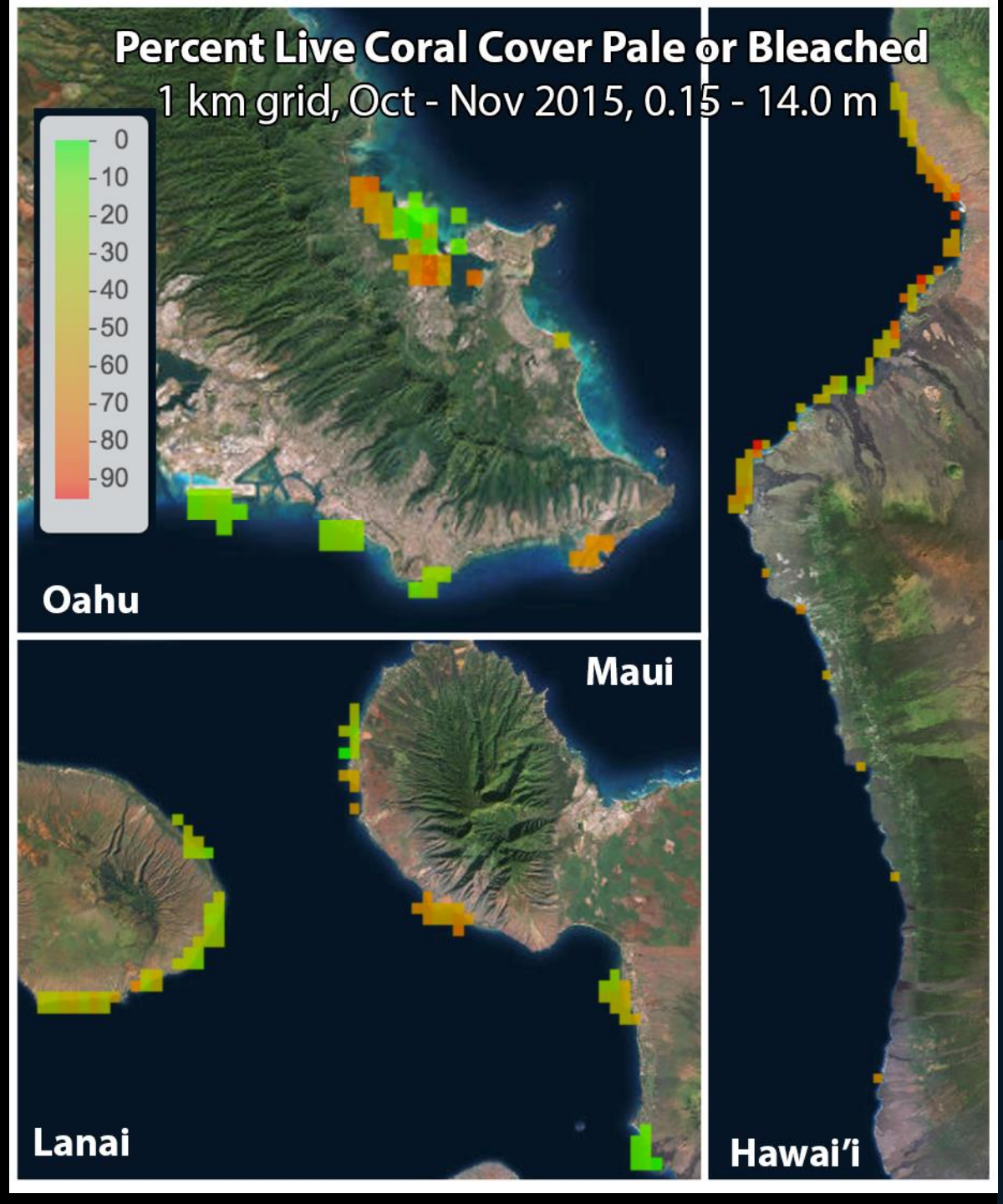

Parameter Relative Importance,
Exposure Model Average
Relative Importance
0.0
0.2
0.4
0.6
0.8
Degree Heating Weeks
Depth
PARz 2015 mean
K490 2015 mean weekly range
SST 2015 mean weekly range
PAR 2015 mean
PARz 2015 max
K490 2015 max
Wave Energy 1979−2012
PAR 2015 mean weekly range
PARz 2015 mean weekly range
SST 2015 mean
PAR 2015 max
SST 2015 max
K490 2015 mean
Hypothesized Exposure Driver


A.
Exposure Model Predicted vs
Observed Percent Coral Affected
Pred. vs Obs R2 = 51.56%
Observed Percentage of Live Coral Affected
Exposure Predicted Percentage of Live Coral Affected
0
25
50
75
100
Island and Region
Hawaii_Kohala
Hawaii_Kona
Hawaii_North_Kona
Lanai_E_Lanai
Lanai_S_Lanai
Maui_Kihei
Maui_Olowalu
Maui_SW_Maui
Maui_W_Maui
Oahu_Hanauma_Bay
Oahu_Kaneohe
Oahu_Lanikai
Oahu_Leeward_Oahu


A.
Exposure Model Predicted vs Observed Percent Coral Affected
Pred. vs Obs R2 = 51.56%
Observed Percentage of Live Coral Affected
Exposure Predicted Percentage of Live Coral Affected
Island and Region
Hawaii_Kohala
Hawaii_Kona
Hawaii_North_Kona
Lanai_E_Lanai
Lanai_S_Lanai
Maui_Kihei
Maui_Olowalu
Maui_SW_Maui
Maui_W_Maui
Oahu_Hanauma_Bay
Oahu_Kaneohe
Oahu_Lanikai
Oahu_Leeward_Oahu
B.
Degree Heating Weeks (5 km – CRW ver3)
Residuals Around Percent Live Coral Affected
Degree Heating Weeks (DHW)
C.
Photosynthetically Active Radiation (at Depth – 4 km MODIS)
Residuals Around Percent Live Coral Affected
Max. PAR at Depth 2015 (Einstein m−2 d−1)
D.
Depth of Reef (meters)
Residuals Around Percent Live Coral Affected
Depth (m)

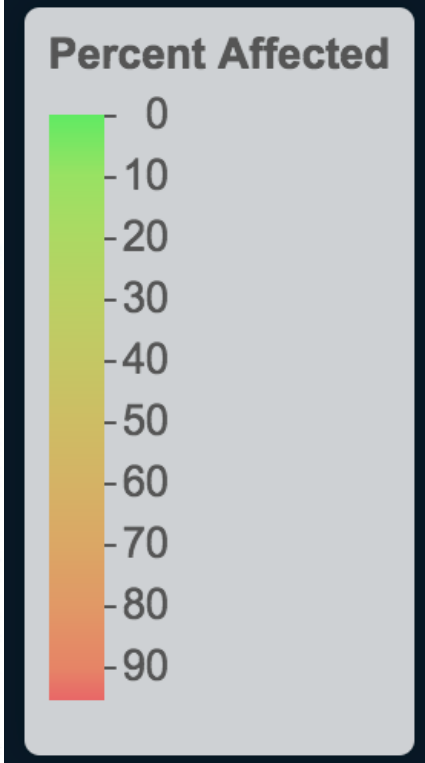
What ***Areas*** Showed Particular Sensitivity or Resistance to Bleaching?

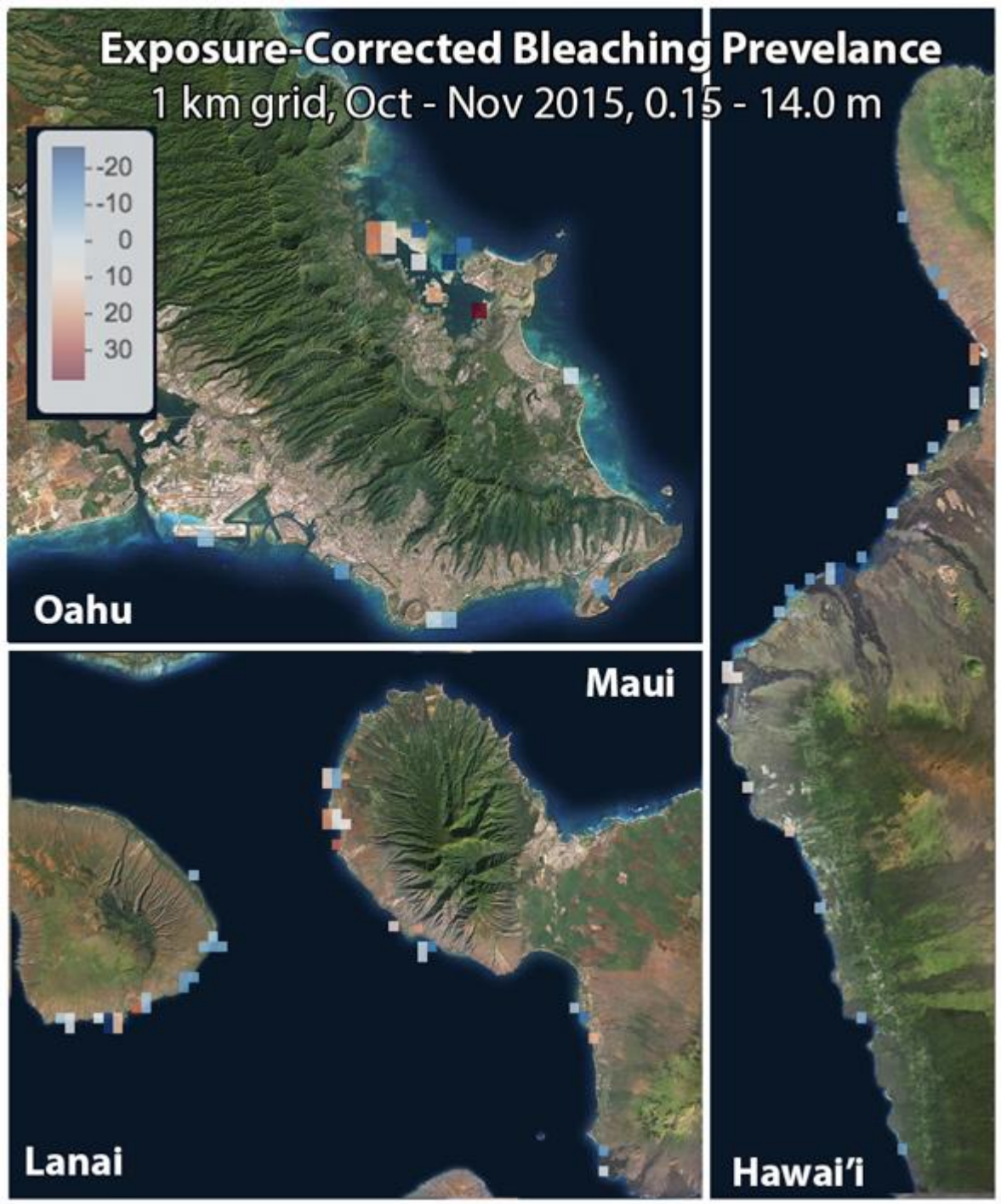

A.
Exposure Model Predicted vs Observed Percent Coral Affected
Pred. vs Obs R2 = 51.56%
Higher Bleaching Than We'd Expect
Sensitive
Residual
Lower Bleaching Than We'd Expect
Resistant
Island and Region
Hawaii_Kohala
Hawaii_Kona
Hawaii_North_Kona
Lanai_E_Lanai
Lanai_S_Lanai
Observed Percentage of Live Coral Affected
Exposure Predicted Percentage of Live Coral Affected
0
25
50
75
100



HCBC Gridded Data

- 2015/10-11
- 1 km grid
- *% Live Coral Cover Pale or Bleached*

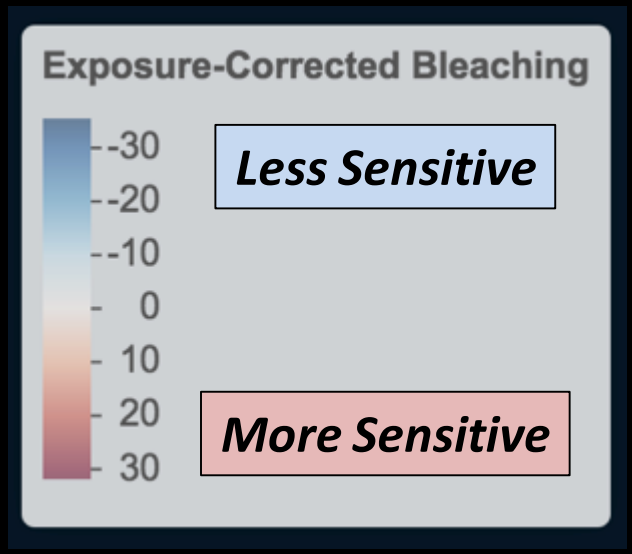




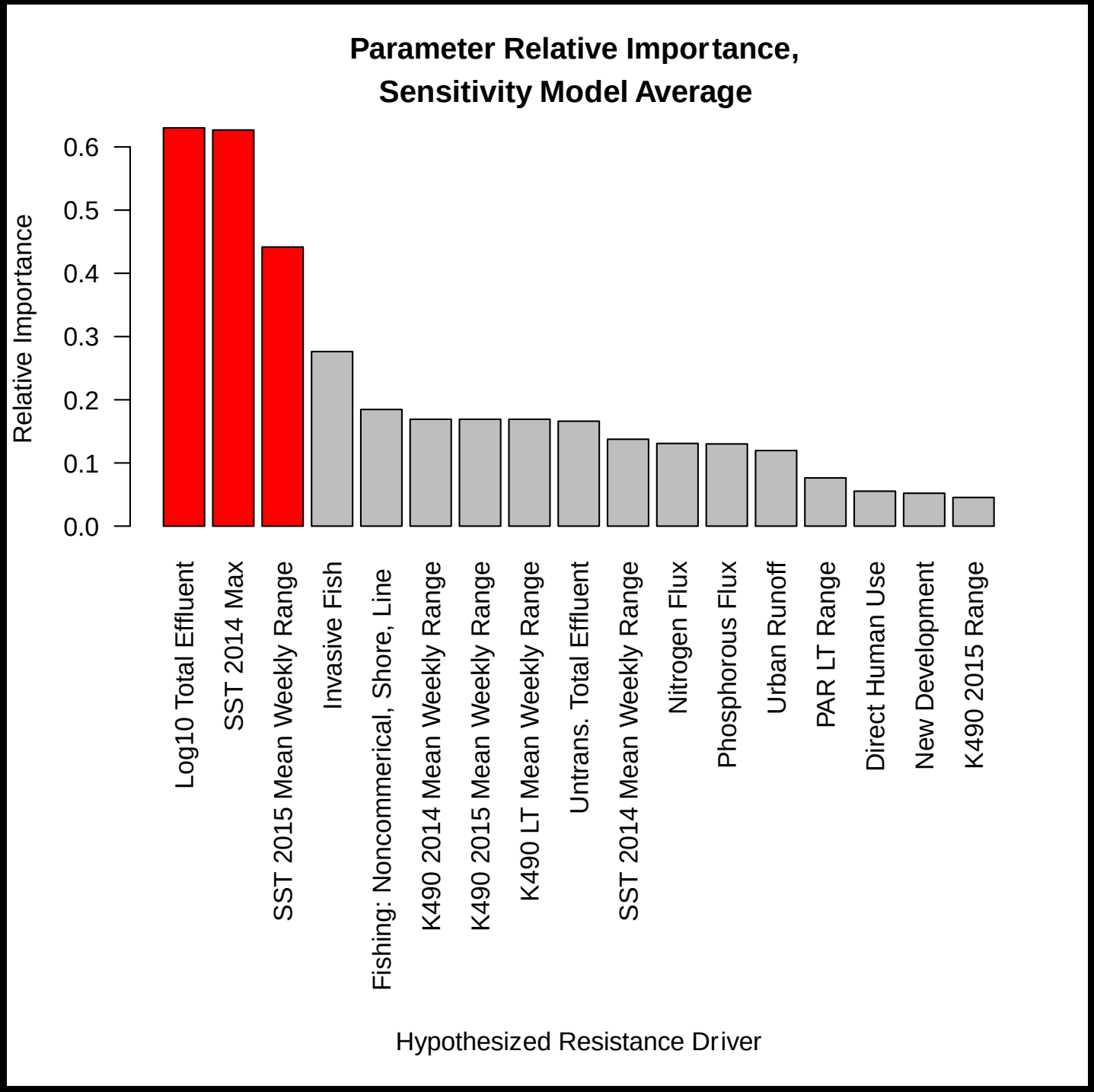
Exposure Corrected Bleaching Prevalence

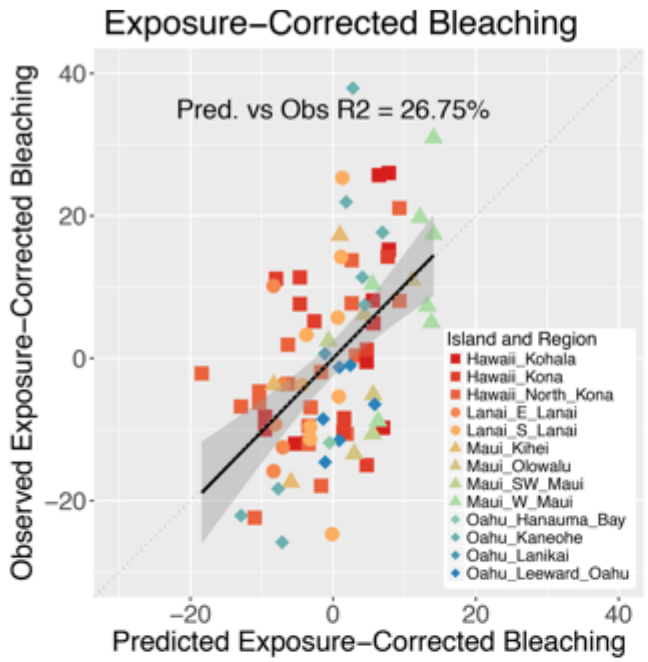
= Sensitivity Proxy

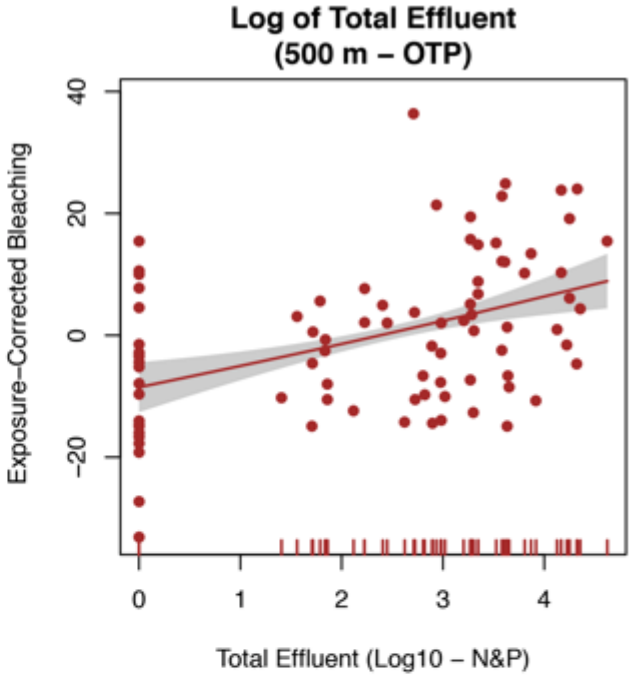
- *Residuals from Exposure Model*

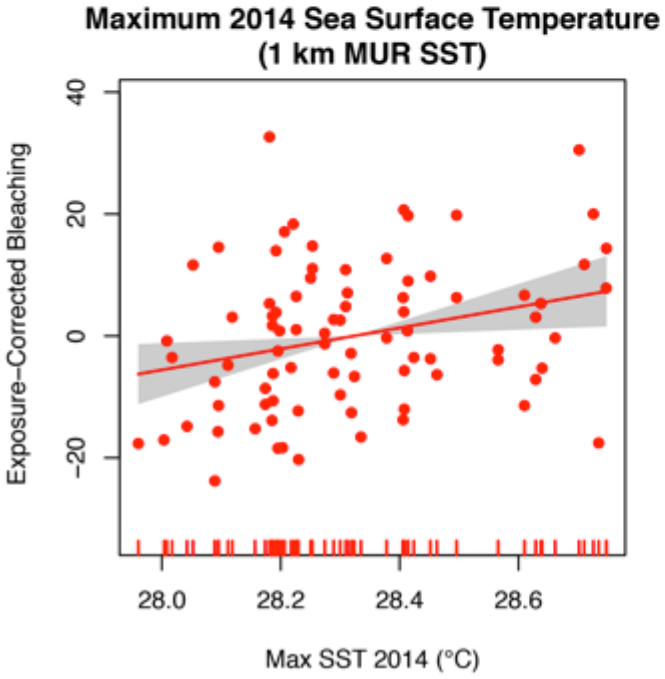


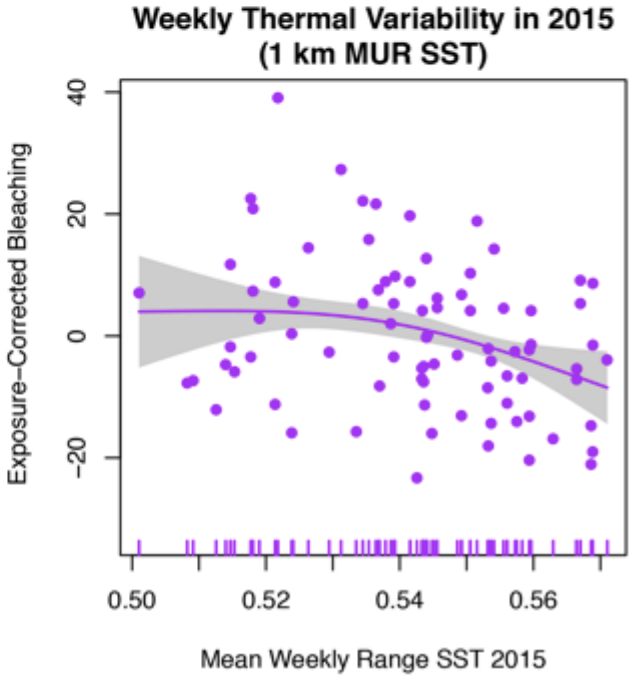
What Drivers ***Predict*** Resistance or Sensitivity to Bleaching?


Parameter Relative Importance,
Sensitivity Model Average
Relative Importance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Log10 Total Effluent
SST 2014 Max
SST 2015 Mean Weekly Range
Invasive Fish
Fishing: Noncommerical, Shore, Line
K490 2014 Mean Weekly Range
K490 2015 Mean Weekly Range
K490 LT Mean Weekly Range
Untrans. Total Effluent
SST 2014 Mean Weekly Range
Nitrogen Flux
Phosphorous Flux
Urban Runoff
PAR LT Range
Direct Human Use
New Development
K490 2015 Range
Hypothesized Resistance Driver


Exposure–Corrected Bleaching
Pred. vs Obs R2 = 26.75%
Observed Exposure–Corrected Bleaching
Predicted Exposure–Corrected Bleaching
Island and Region
Hawaii_Kohala
Hawaii_Kona
Hawaii_North_Kona
Lanai_E_Lanai
Lanai_S_Lanai
Maui_Kihei
Maui_Olowalu
Maui_SW_Maui
Maui_W_Maui
Oahu_Hanauma_Bay
Oahu_Kaneohe
Oahu_Lanikai
Oahu_Leeward_Oahu


Log of Total Effluent
(500 m – OTP)
Exposure–Corrected Bleaching
Total Effluent (Log10 – N&P)


Maximum 2014 Sea Surface Temperature
(1 km MUR SST)
Exposure–Corrected Bleaching
Max SST 2014 (°C)


Weekly Thermal Variability in 2015
(1 km MUR SST)
Exposure–Corrected Bleaching
Mean Weekly Range SST 2015

Model Both ***Exposure*** and ***Resistance***

Bleaching Prevalence

Exposure Model: *52%*

Exposure Model *Residuals*: Sensitivity Proxy

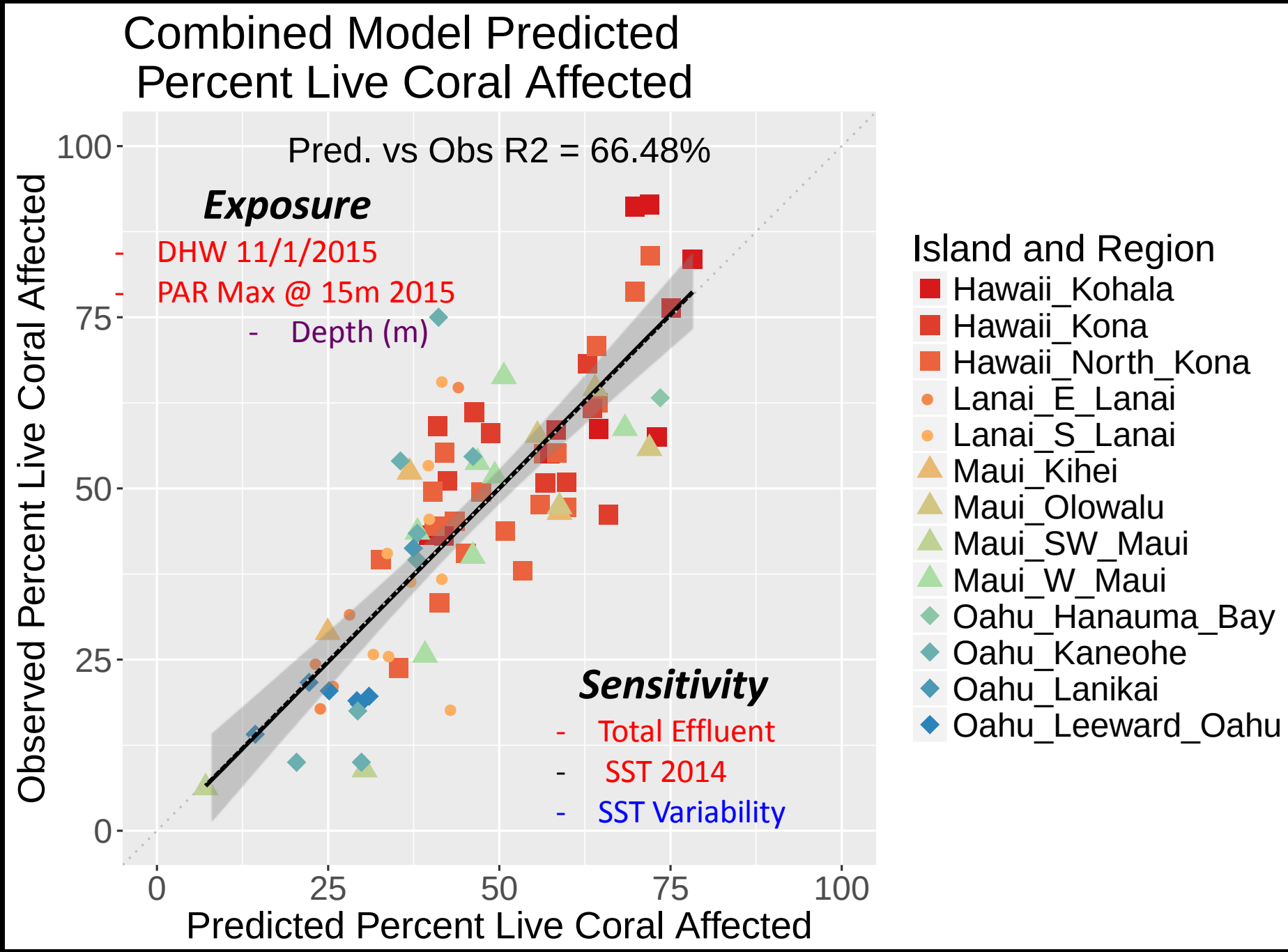
Sensitivity Model: *27%*

Drivers of Realized Sensitivity

Combined Model: 67%

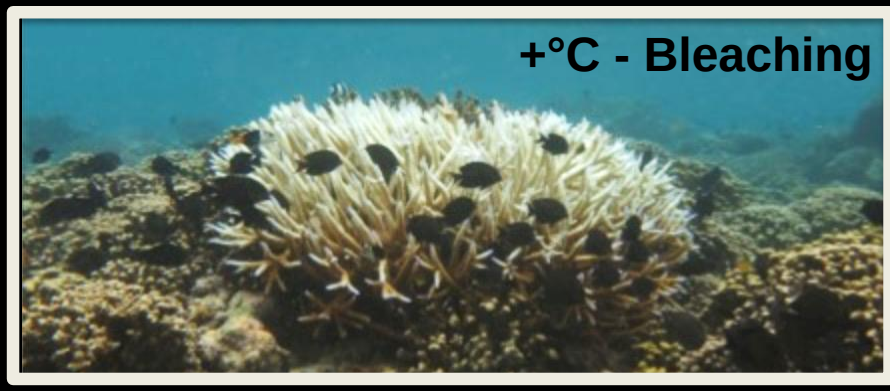
BIC Best

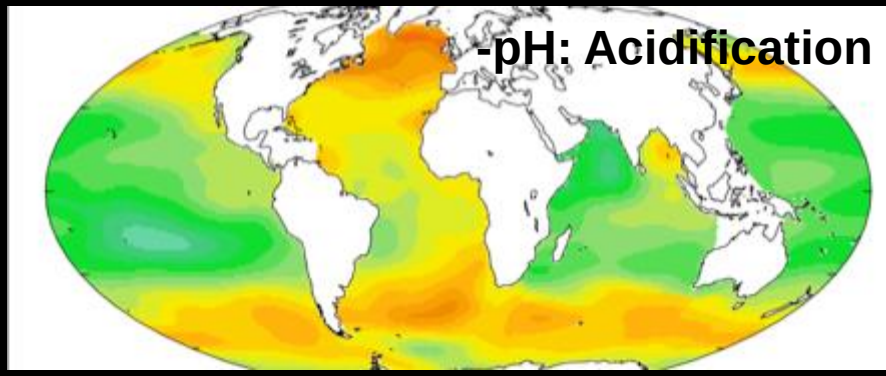
GAM Modeling, Model Selection, Weighted Model Averaging

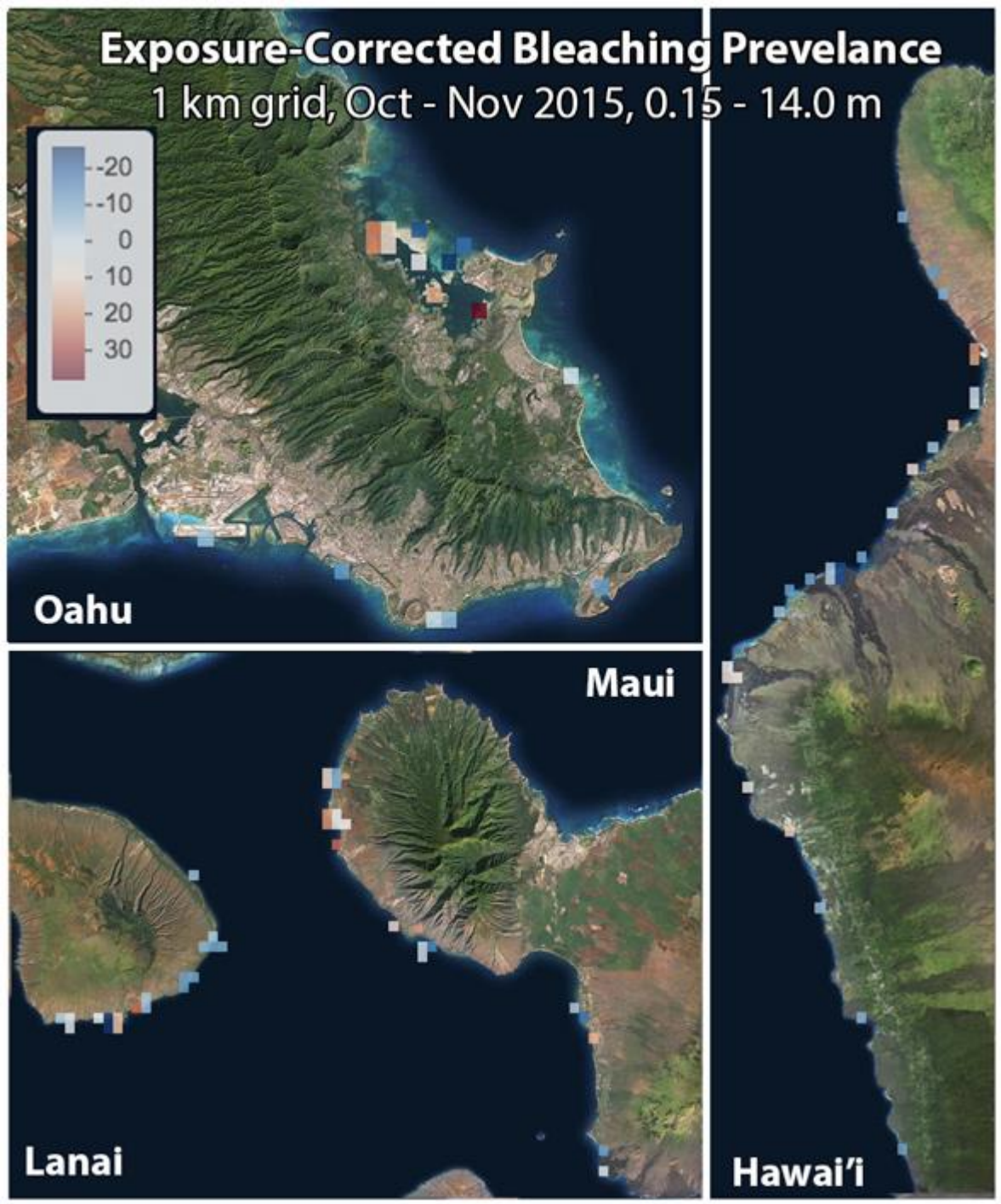

Combined Model Predicted
Percent Live Coral Affected
Pred. vs Obs R2 = 66.48%
Exposure
- DHW 11/1/2015
- PAR Max @ 15m 2015
- Depth (m)
Sensitivity
- Total Effluent
- SST 2014
- SST Variability
Observed Percent Live Coral Affected
Predicted Percent Live Coral Affected
0
25
50
75
100
Island and Region
Hawaii_Kohala
Hawaii_Kona
Hawaii_North_Kona
Lanai_E_Lanai
Lanai_S_Lanai
Maui_Kihei
Maui_Olowalu
Maui_SW_Maui
Maui_W_Maui
Oahu_Hanauma_Bay
Oahu_Kaneohe
Oahu_Lanikai
Oahu_Leeward_Oahu

Short-Term & Local

Long-Term & Global



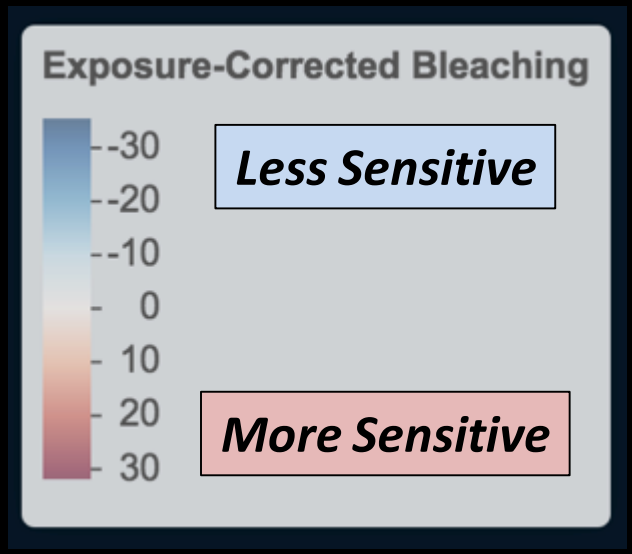




Exposure Corrected Bleaching Prevalence

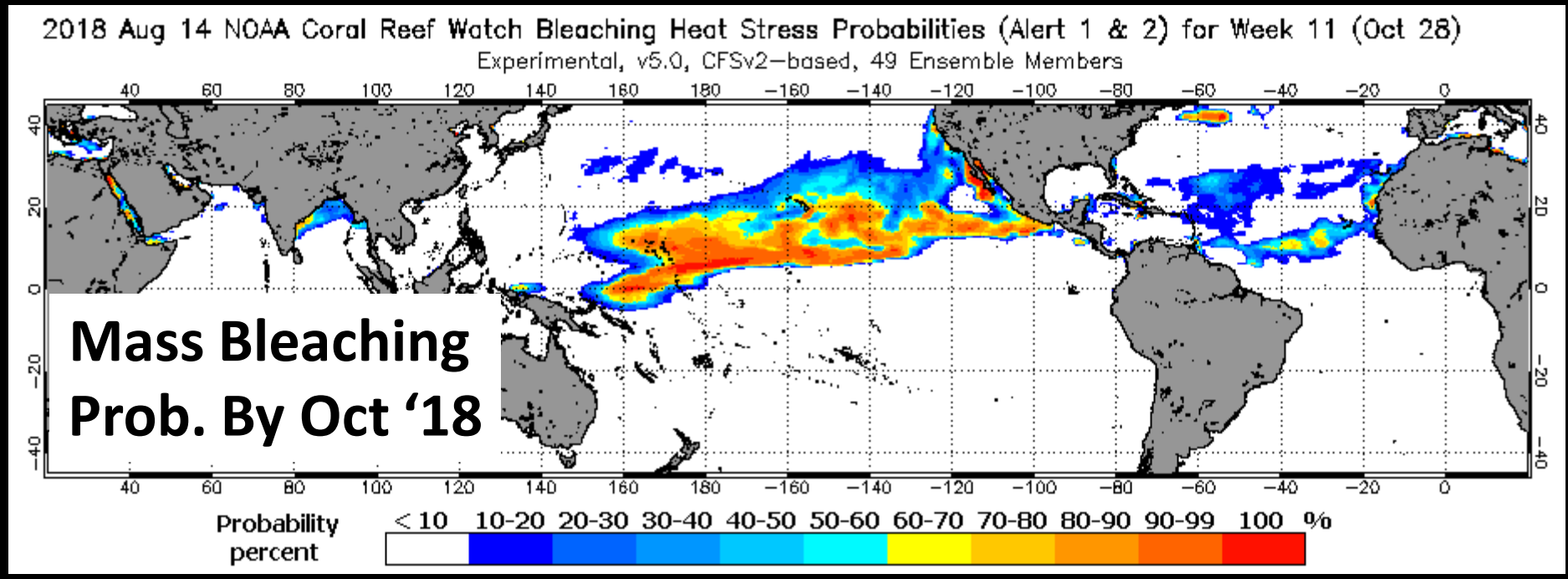
= Sensitivity Proxy

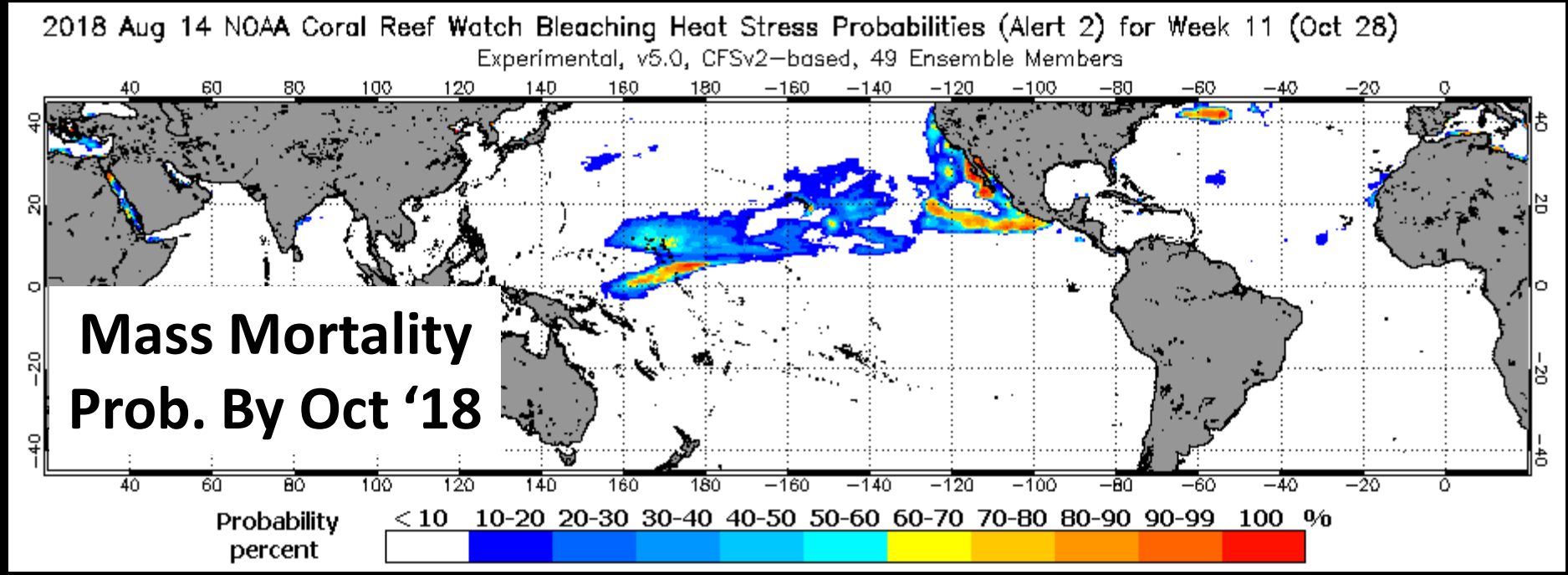
- *Residuals from Exposure Model*



Sewage Exposure correlates significantly with corals' sensitivity to bleaching.

- Bleaching has significant impacts globally and in Hawaii
  - loss of ~ 30% of surveyed live coral cover, 2015
- Exposure to temperature stress (with light) drives response.
- Sewage Exposure and Thermal History correlate significantly with sensitivity.
- Thermal stress exposure will likely continue for decades to come.


2018 Aug 14 NOAA Coral Reef Watch Bleaching Heat Stress Probabilities (Alert 1 & 2) for Week 11 (Oct 28)
Experimental, v5.0, CFSv2–based, 49 Ensemble Members
Mass Bleaching
Prob. By Oct '18
Probability percent
< 10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 90-99 100 %


2018 Aug 14 NOAA Coral Reef Watch Bleaching Heat Stress Probabilities (Alert 2) for Week 11 (Oct 28)
Experimental, v5.0, CFSv2–based, 49 Ensemble Members
Mass Mortality
Prob. By Oct '18
Probability percent
< 10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 90-99 100 %

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